ASD TECHNICAL REPORT 61-345

EFFECT OF JET FUEL ADDITIVES ON FILTERABILITY AND WATER SEPARATION CHARACTERISTICS

ROBERT K. JOHNSTON
J. P. CUELLAR, JR.

SOUTHWEST RESEARCH INSTITUTE

JUNE 1961

AERONAUTICAL SYSTEMS DIVISION

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Robert K. Johnston
J. P. Cuellar, Jr.

Southwest Research Institute

JUNE 1961

Applications Laboratory
Directorate of Materials and Processes
Contract No. AF 33(600)-39425
Project No. 3048
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AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

FOREWORD

This report was prepared by Southwest Research Institute, San Antonio, Texas, under Contract No. AF 33(600)-39425. This contract was initiated under Project No. 3048, "Aviation Fuels," Task No. 30178, "Effects of Fuel on Fuel Systems." The work was administered under the direction of the Applications Laboratory, Directorate of Materials and Processes, Deputy for Technology, Aeronautical Systems Division, with Mr. Paul C. Linder as Project Engineer.

This report covers work performed from May 1959 through November 1960. The contract was performed by the Department of Aerospace Propulsion Research, Southwest Research Institute, under the technical direction of Mr. Robert K. Johnston, Project Leader.

The following filter-separator manufacturers furnished design information, test elements, and other equipment; their cooperation is gratefully acknowledged:

Bendix Filter Division
Bowser, Inc.
Briggs Filtration Company
Permanent Filter Corporation
Richmond Engineering Company
Warner Lewis Company

ABSTRACT

The effect of corrosion inhibitors on filtration and water separation characteristics of JP-4 fuel was studied in a single-element filter-separator test facility, using five types of commercial elements and housings designed to simulate full-scale flow conditions. Standard coarse A/C dust and water were used as test contaminants; a brief study was made using iron oxides. Adverse effects of the corrosion inhibitors varied widely, and the element types differed in efficiency and modes of failure.

The CRC water separometer, a bench-scale apparatus, gave a general correlation with the single-element results. Interaction of additives with fuel constituents caused difficulty in early work, but otherwise the separometer repeatability was satisfactory. Preliminary work on a reference fluid indicated that an "odorless solvent" may be suitable.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Marc P. Dunnam

MARC P. DUNNAM
Chief, Fuels and Lubricants Branch
Nonmetallic Materials Laboratory

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I. INTRODUCTION

In recent years the cleanliness of aircraft fuel has become a major concern of both military and commercial consumers. Aircraft gas-turbine engines are particularly sensitive to fuel contamination because of the precision fuel systems used by these engines. Further, fuel system freezeups caused by water have become a major problem as flight altitudes are increased Jet fuels are relatively difficult to decontaminate (compared to gasoline) because of higher density and viscosity. Various types of filter-separators are used in ground fuel-handling facilities to filter out solid contaminants and to coalesce and separate water from the fuel. Although the designs and sizes of such units vary widely, most modern filter-separator units are similar in (a) the use of Fiberglas elements for filtering out solids and coalescing water, and (b) the presence of some type of barrier material as a "second stage" or "separator," to prevent carryover of water droplets.

It has been observed that some corrosion inhibitors used in jet fuels can impair the operation of such filter-separator units. These corrosion inhibitors, which are governed by the specification MIL-I-25017, were introduced several years ago for mitigating pipeline and equipment corrosion. Unfortunately, insufficient attention was given to their effects on fuel-handling properties. The only control on emulsifying properties of the inhibitors was the relatively simple "interaction with water" test, which proved to be completely inadequate to predict the detrimental effects shown by many corrosion inhibitors. Since commonly used corrosion inhibitors are surface-active materials, their possible undesirable effects include promotion of emulsions, dispersion of solids, reduction of interfacial tension, and aggravation of the plugging tendency of filter elements.

In connection with these and associated problems, Southwest Research Institute under Air Force sponsorship has been engaged in an evaluation of the effect of additives on the performance of filter-separators. A test facility was constructed and small-scale housings were designed to simulate fuel flows and velocities typical of full-scale equipment. The elements of five manufacturers were included in the program. Tests at standardized conditions have been conducted using the various MIL-I-25017 corrosion inhibitors and several test dusts.

To meet the need for a small-scale test to evaluate and screen fuels and additives for water-separating characteristics, a test apparatus was designed at the Naval Research Laboratory and developed through CRC joint action. This apparatus is now available commercially as the "CRC Water Separometer."

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Results are presented in this report on the initial operation of one of these units, including studies of test repeatability and degree of correlation with the single-element filter-separator test results.

II. TEST FUELS AND ADDITIVES

A Gulf Coast JP-4 fuel from Howell Refining Company has been the primary base fuel used for both the single-element and the separometer tests. This fuel is an untreated straight-run distillate from sweet crude; inspection data are shown in Table 1. A portion of this fuel was provided for use in CRC programs under the designation RAF 151-60.

A high-aromatics JP-4 was prepared by Ashland Oil and Refining Company for use in single-element testing. Inspection data on this fuel are also given in Table 1. This fuel conforms to JP-4 specifications in all respects; density and aromatics content are near the maximum limits.

In addition to the Howell JP-4, several other fuels were used in the separometer tests, as follows

- Commercial aircraft turbine fuel (Esso)
- Sovasol 35 (Socony Mobil)
- WS-3750 (Esso)
- Soltrol 130 (Phillips)
- Bayol D (Esso)
- HTF-27 (special fuel, isopropylbicyclohexyl)

The fuel additives used in this program were as follows

Code A through N (12 additives)	Corrosion inhibitors, MIL-I-25017 (past or present QPL); maximum allowable concentration 16 or 20 lb/1000 bbl
Code O	Experimental combination additive (anti-icing and antirust) supplied by Navy AEL, tested at 20 lb/1000 bbl
Code P	Anti-icing additive P55 MB, tested at 0.1% (vol)
Code Q	Anti-icing additive (hexamethylene glycol); tested at 0.5% (vol)

The group of corrosion inhibitors included essentially all of those which had been approved under MIL-I-25017 at any time up to the end of this program, including several which had been withdrawn. It should be noted that almost all of the work in this program was done at "maximum allowable concentration" as defined for each inhibitor in MIL-I-25017. The few tests run at different concentrations are specifically identified in this report.

TABLE 1. JP-4 FUEL INSPECTIONS

(Suppliers' Data)

	Howell[a]	Ashland
Gravity, °API	50.2	47.7
R. V. P., psi	2.95	2.3
Existent gum, mg/100 ml	0.4	0.2
Potential gum, mg/100 ml	0.4	3.9
Aromatics, FIA, %	12.1	24.0
Olefins, FIA, %	0.76	3.5
Sulfur, total, %	0.0137	0.03
Sulfur, mercaptan, %	Nil	0.001-
Doctor test	Sweet	Sweet
Distillation, ASTM D86		
IBP, °F	139	140
10%, °F	198	246
% at 290°F	50	30
% at 370°F	73[b]	76
% at 400°F	80	90.5
% at 470°F	93[b]	98.5
FBP, °F	505	474
Residue, %	1.3	1.0
Loss, %	0.7	0.5
Freezing point, °F	-78	-80-
Aniline-gravity constant	6000	5285
Smoke point, mm	22	18
Smoke-volatility index	53.6	55.8
Copper strip corrosion	No. 1	1A
Water reaction test		
Volume change, ml	--	--
Interface rating	1	1
Thermal stability		
ΔP, "Hg	--	0.1
Preheater rating	--	1
IFT, dynes/cm[c]	42.8	41.4

(a) A portion of this fuel was set aside for use in the CRC water separometer program under designation RAF 151-60.

(b) Interpolated from distillation data.

(c) SwRI results on samples from storage tank.

A relatively minor amount of work was done on Additives O, P, and Q. Additive O was included as a "bad" material for a baseline in correlating the single-element and separometer tests, Additives P and Q were included in a few separometer runs as a matter of interest.

The corrosion inhibitors were checked (in Gulf Coast JP-4 at the maximum allowable concentration) for "water reaction" test as required by the fuel specification MIL-J-5624E. The results of these evaluations, as shown in Table 2, indicate that the presence of the inhibitors at maximum concentration had almost no effect on the water reaction ratings.

TABLE 2. EFFECT OF CORROSION INHIBITORS ON WATER REACTION

Gulf Coast JP-4 fuel

Additive[a]	Water Reaction Test[b]: Interface Rating	ΔV, ml
A	1	0
B	1	0
C	1	0
D	1	0
E	1	0
F	1	0
G	1[c]	0.5
H	1[c]	1.0
J	1	0
K	1	0
L	1	0
None	1	0

(a) Maximum allowable concentrations per MIL-I-25017.
(b) Using phosphate buffer, pH = 7.
(c) Interface was clean, however, drops of water remained on cylinder.

III. SINGLE-ELEMENT FACILITY PROGRAM

A. Test Equipment

1. Test Stand

The test facility constructed for this project, shown schematically in Figure 1, consists of a fuel reservoir, test filter, and circulating pump, plus the necessary equipment for metering fuel flow, injecting water and solids, and measuring fuel temperatures and pressures.

The fuel reservoir is a truck-mounted 500-gallon aluminum tank connected to the test system by rubber hoses, so that fresh fuel can be brought from the fuel storage area to the test area for each test. A photograph of the test facility with the fuel reservoir in operating position is shown in Figure 2.

The test stand components on the influent side of the test filter are shown in Figure 3. These include the water metering system, main fuel pump, heat exchangers, fuel flowmeter, line screen for emulsifying the water, dust feeder, dust-fuel mixing bowl, dust injection pump, influent sight glass, influent sampler, and the necessary plumbing and control valves. A test filter and the effluent-side components of the test stand are shown in Figure 4. These include the effluent sampler, effluent sight glass, orifice-type fuel flowmeter, manometers, and the associated plumbing and control valves. All piping is aluminum, and the fuel system is entirely nonferrous except the case of the main fuel circulating pump.

Many of the test-stand components are standard items and do not require further comment. The main fuel circulating pump is a rotary type with internal bypass for pressure control, rated at 40 gpm at 40 psi. The dust feeding and injecting system consists of a ratchet-type variable-speed drive on an auger feeding dust into the mixing bowl; accuracy of dust feed is ± 10% over the range of 1 to 20 g/min. Fuel is drawn into the dust mixing bowl and the fuel-dust mixture is injected into the main fuel line by a helical-screw (rubber stator) pump of the Moyno type.

A light meter was designed and installed on the effluent sight glass, as shown in Figures 5 and 6. The instrument is mounted with the lamp and "solar cell" on opposite faces of the effluent sight glass, solids or water in the fuel stream cut down the light transmittance and hence the output of the cell. The input to the lamp is controlled by a constant-voltage transformer through a 6.5-volt stepdown transformer. The solar cell output is measured by a millivoltmeter, the emf having proved to be a more

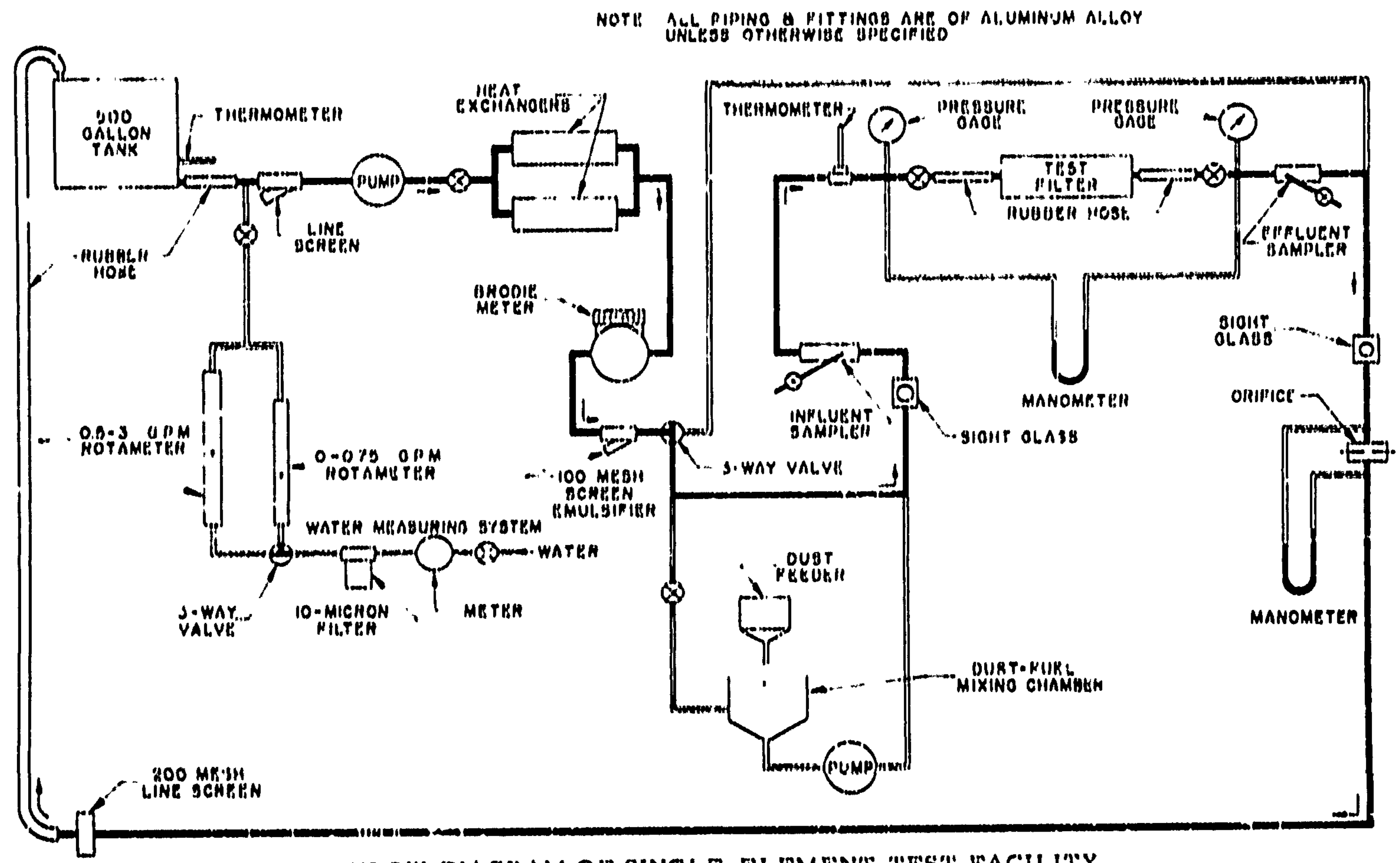


FIGURE 1 FLOW DIAGRAM OF SINGLE-ELEMENT TEST FACILITY

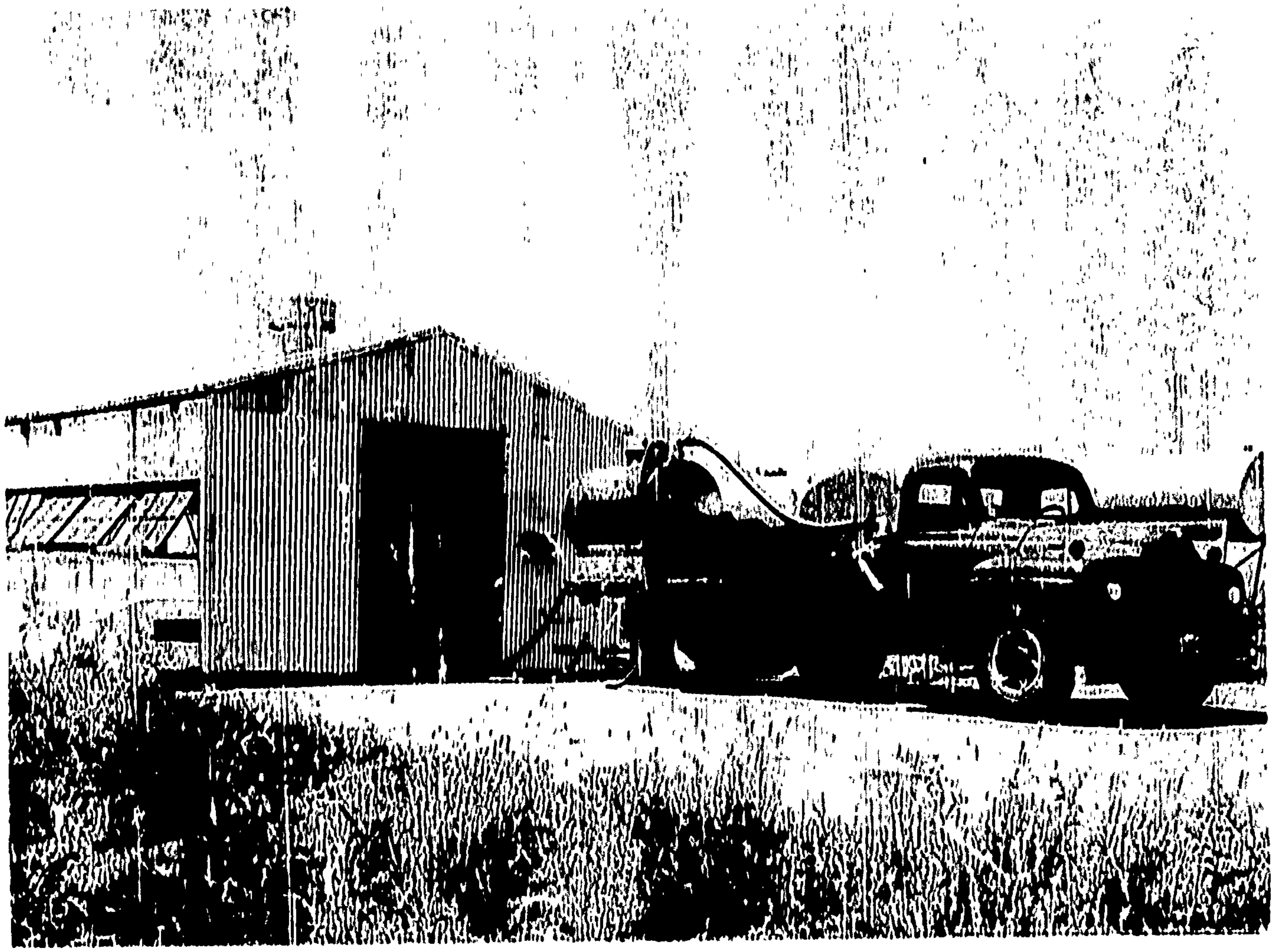


FIGURE 2   OUTSIDE VIEW OF SINGLE-ELEMENT TEST FACILITY SHOWING TRUCK-MOUNTED FUEL RESERVOIR IN OPERATING POSITION

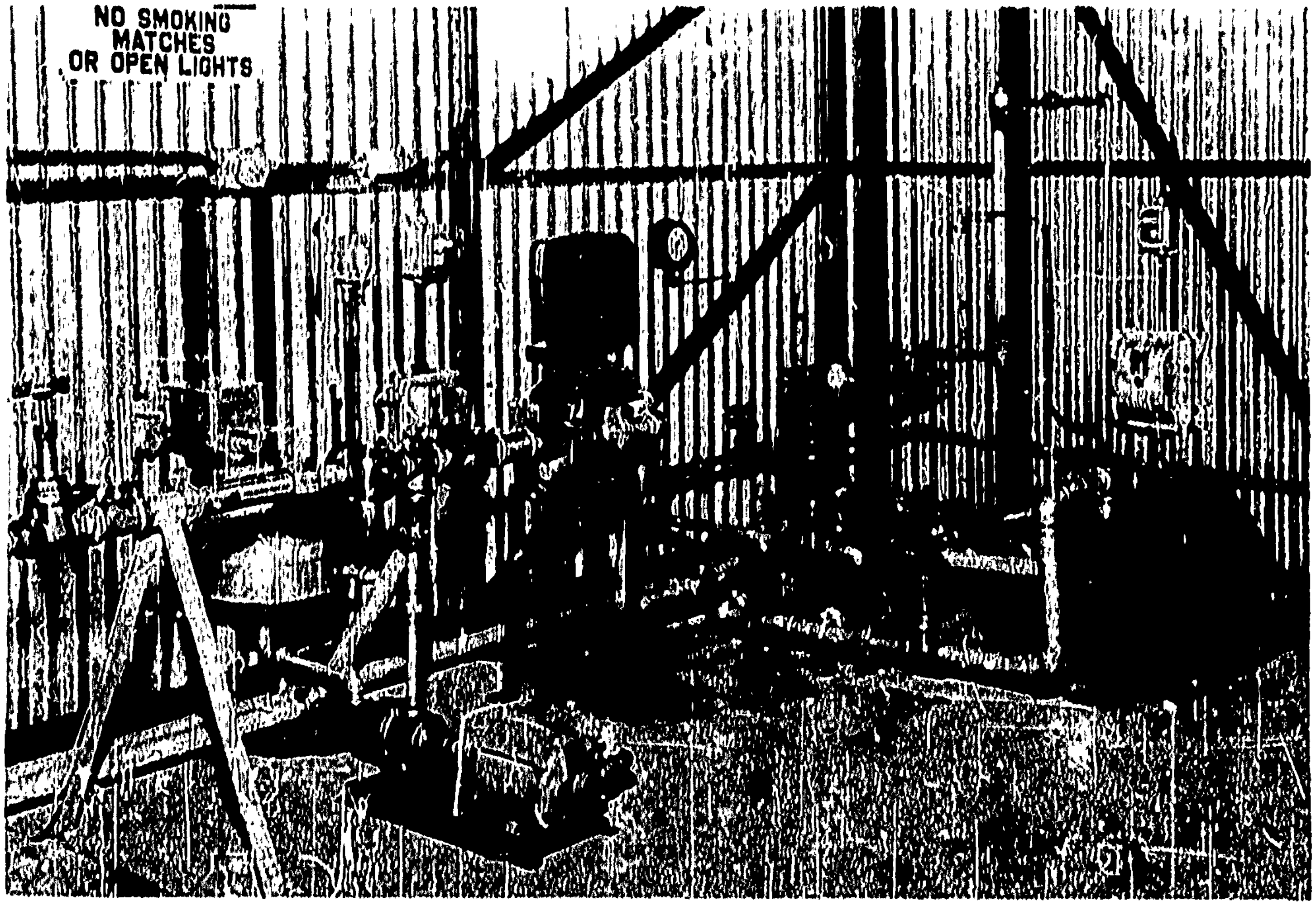


FIGURE 3 TEST STAND (INFLUENT-SIDE COMPONENTS)

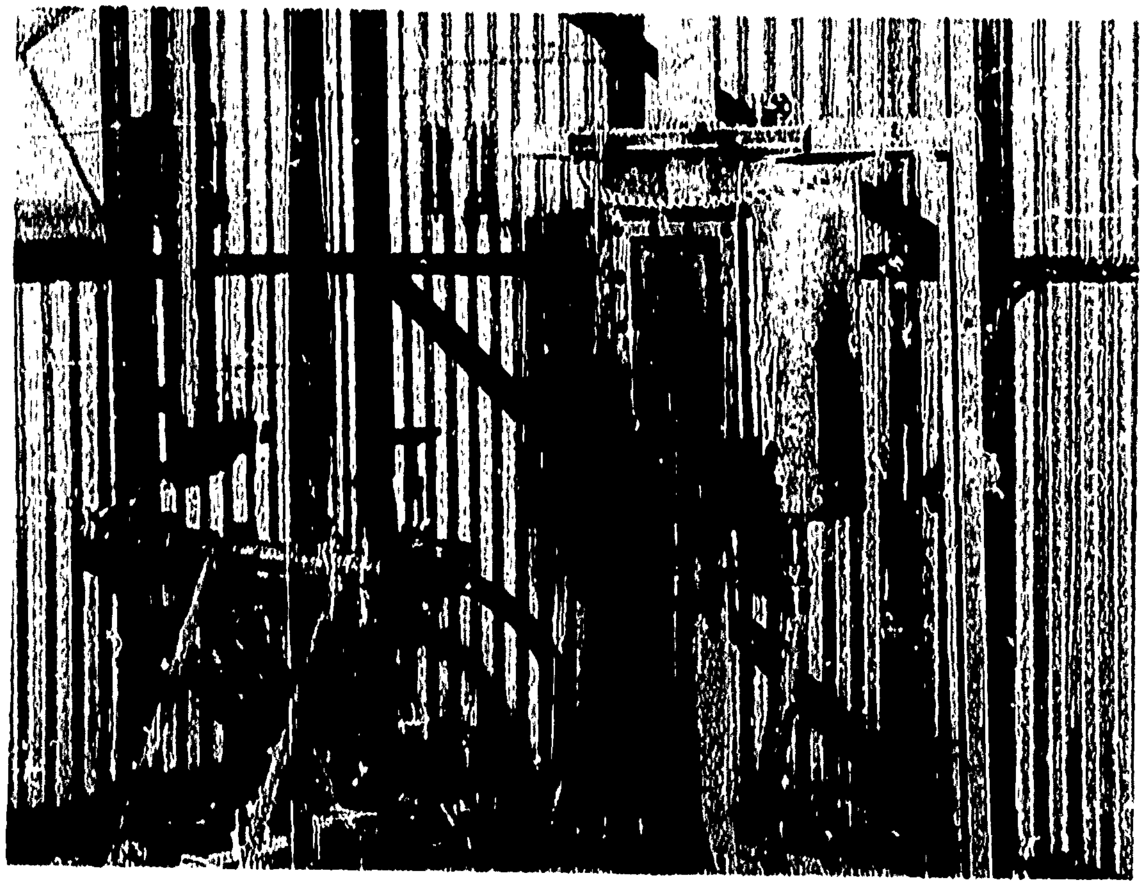


FIGURE 4. TEST FILTER AND EFFLUENT-SIDE COMPONENTS

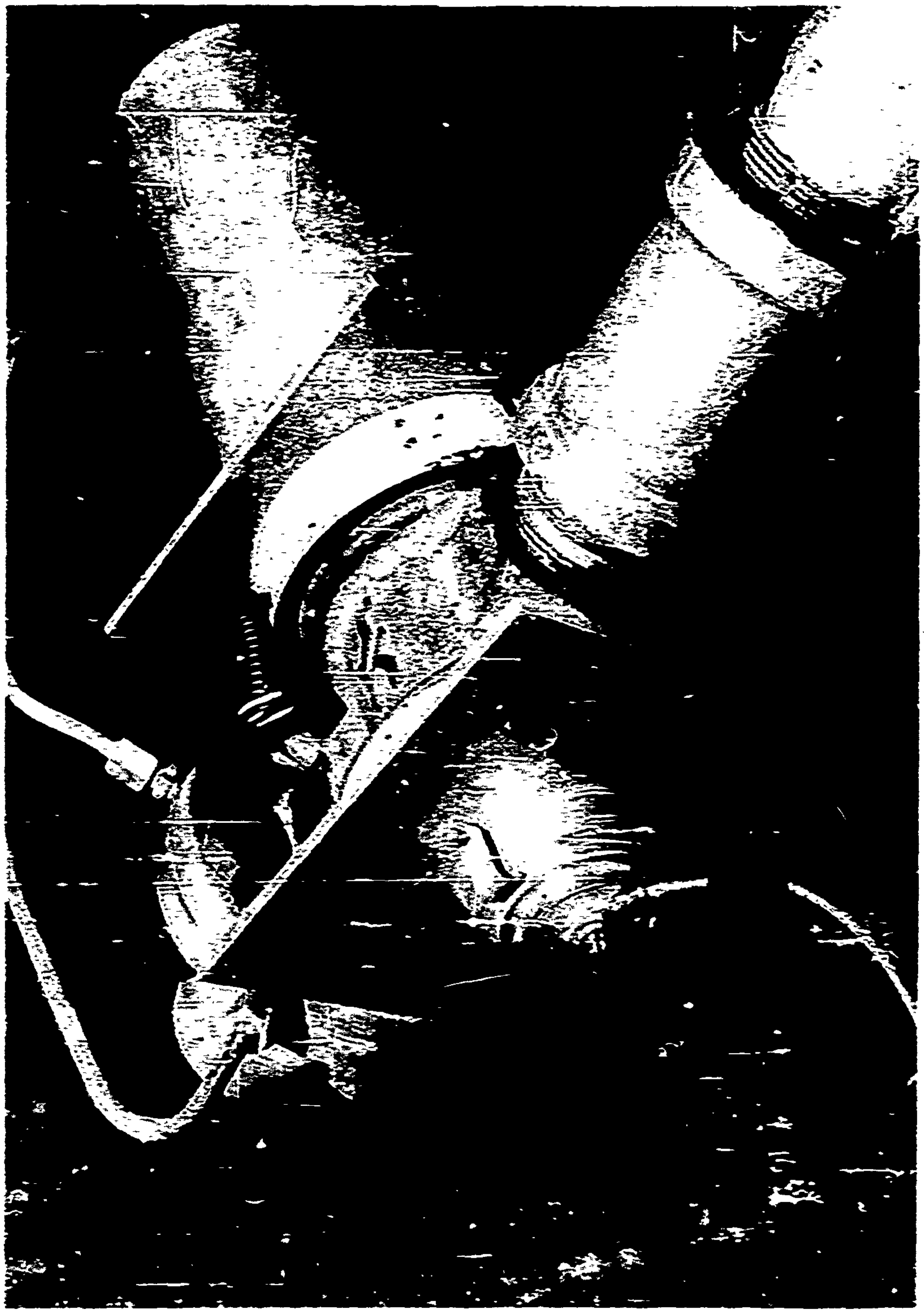
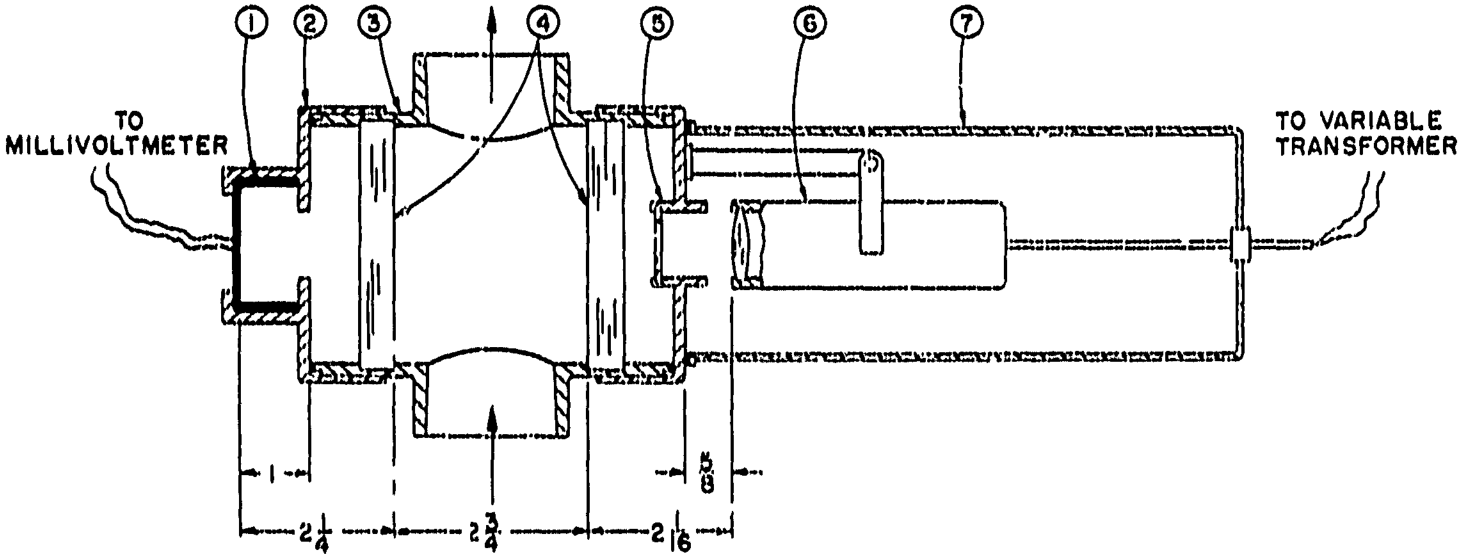


FIGURE 5. LIGHT METER INSTALLED IN EFFLUENT LINE



① HOFFMAN SILICON SOLAR CELL TYPE S-1A, MOUNTED IN KODAK LENS HOOD SERIES VI
② SOLAR CELL HOUSING
③ SCHUTTE & KOERTING MODEL 1802, 1-1/2" FLOW INDICATOR (FLAPPER REMOVED)
④ SIGHT-GLASS WINDOW
⑤ VAPOR SEAL WITH WINDOW
⑥ AMERICAN OPTICAL UNIVERSAL MICROSCOPE LAMP
⑦ LAMP HOUSING

FIGURE 6. ASSEMBLY SKETCH OF LIGHT METER

sensitive indicator than the current output. This light meter was used in all except the earliest part of the program, and was found to be a reliable and sensitive instrument for detecting filter failure (contamination in the effluent stream). The light meter was built from stock components, and was inexpensive and easy to assemble. Operating experience was very satisfactory; no recalibration, cleaning, nor any type of servicing was required in some 100 tests in which the meter was used.

2. Filter-Separator Housings and Elements

In order to provide a representative group of filter-separators for this program, design data and other information were solicited from various manufacturers of 300- and 600-gpm fixed units of the type used in Air Force ground installations. It should be pointed out that most of these full-scale units antedate the use of corrosion-inhibited fuel in qualification testing of filter-separators, therefore, no representations were made by the manufacturers as to performance of the units on such additive-containing fuels.

Five filter-separators were selected as representative of the rather widely different types being used. Element and housing design are not discussed in detail in this report because of proprietary restrictions. However, it is pertinent to note that the five units included one horizontal configuration and three different types of vertical configuration. These configurations will be discussed in more detail in considering the question of the single-element scaledowns. The single-element units are identified in this report as Test Filters I - V.

The elements used in this program were in all cases the full-size elements supplied commercially by the various manufacturers for use in their respective filter-separator units. Although the elements differed rather widely in design, a common feature was the use of Fiberglas in the principal filtering and water-coalescing element. The Fiberglas was fabricated in a variety of forms, including (a) predensified and bonded washer-shaped Fiberglas blocks stacked and end-compressed in assembly, (b) bonded Fiberglas sheets wound in tension around a rigid core of expanded metal or similar material, (c) thin bonded Fiberglas sheets accordion-pleated before winding, and in one case (d) coarse unbonded Fiberglas sheet used for preliminary filtration. In all cases the flow in these particular filtering-coalescing elements was inside-out. The external surfaces of the various elements were fabric and/or perforated metal. Some of the elements included interior windings of fabric or paper, and one of the element types included a porous bronze insert.

In the designs under consideration the function of a final barrier or water separator was performed by a variety of arrangements, including (a) a fabric shroud surrounding the filter-coalescer element, (b) an individual separator element made of treated accordion-pleated paper, and (c) a fine plastic screen

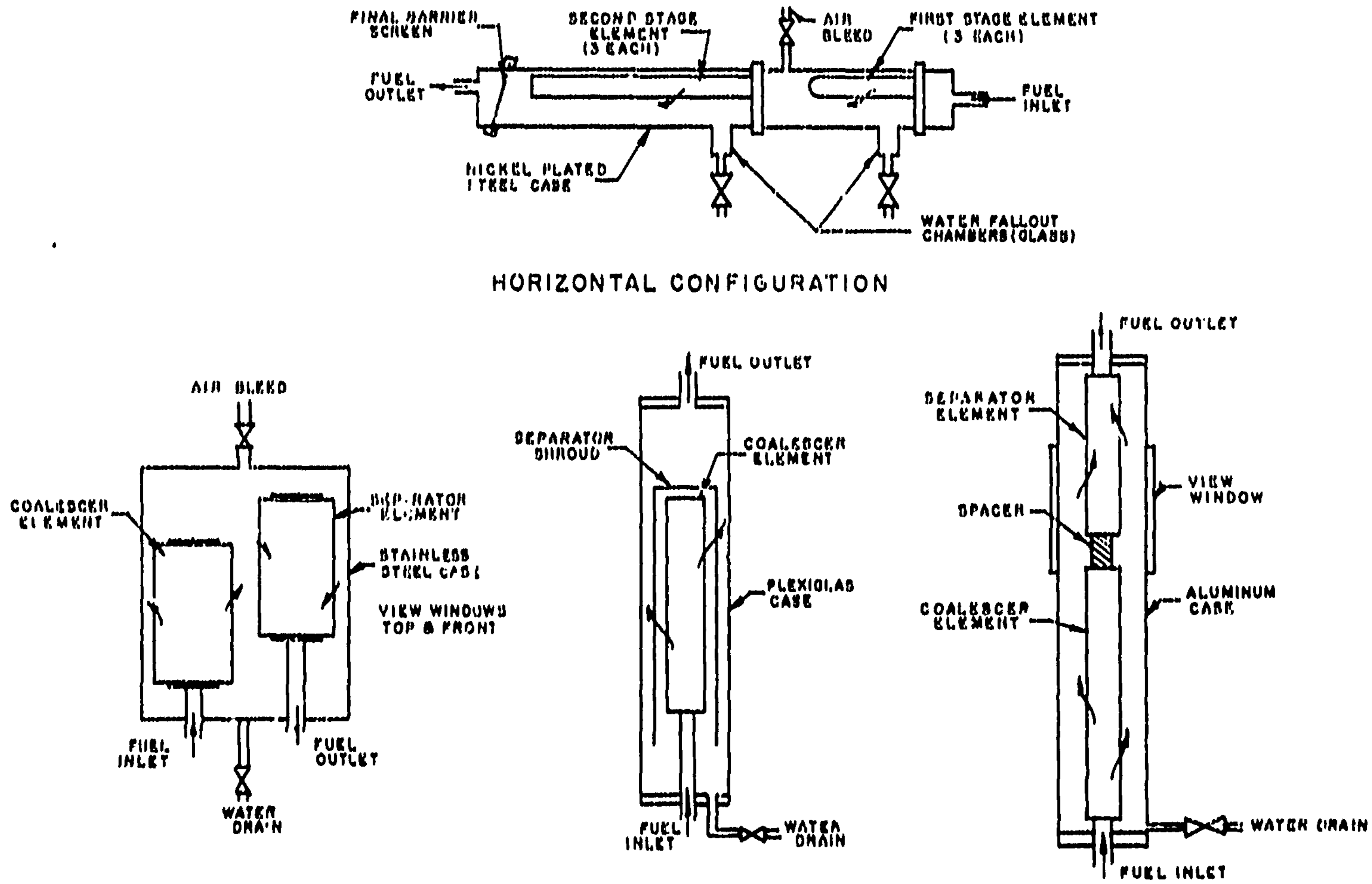
It is pertinent to note that the configurations and elements included in this program did not include any conforming to the new DOD filter-separator specification, in which the filter-coalescer element has certain standard dimensions and is surrounded by a Teflon-treated metal screen which serves as a separator. At the time of choosing the filter-separator units for this study, elements and design data for the new DOD units were not readily available.

The four general configurations of the scaled-down units are shown in Figure 7 (of the five units, two were of the same configuration). The rated flows for the units all fell within the range of 17 to 25 gpm. In the case of the horizontal-configuration unit it was necessary to use a three-element design to fall within this range of flowrates; for convenience in terminology, this unit is included in the general class of "single-element" units. The element flow ratings are those furnished by the respective manufacturers. In the units with individual separator elements (vertical side-by-side and vertical suspended configurations), it was found that in each case the manufacturer's rated flow for the separator element was greater than for the coalescer (i.e., the full-scale unit used fewer separators than coalescers). In the single-element units the mismatches were corrected by blocking a portion of each separator element surface with a resin coating.

In addition to the rated flow per element, the other quantity kept constant in the scaledowns was "maximum axial velocity," defined as the maximum fuel velocity component parallel to the major axis of the filter elements. This velocity was calculated for each of the full-scale units, with due allowance for the cross-sectional area occupied by the elements, pipes, and other internal members, and the scaled-down units were designed for the same velocity. This maximum axial velocity ranged from 0.25 to 0.38 ft/sec.

Designing on the basis of maximum axial velocity was not possible in the case of the vertical side-by-side configuration, since the major velocity component is not axial. In this single-element unit the case was designed so that the percentage of the cross-sectional area occupied by the elements was the same as in the full-scale unit; further, the relative positioning of the elements was similar in the small and large units.

The unit configurations and scaledown design procedures have been discussed in some detail because of the question that always exists as to the validity of results obtained in scaled-down units. It is recognized that no single-element unit can duplicate the rather complex conditions of operation of typical full-scale filter-separators. However, it is believed that the careful design of the small units in this program has eliminated most of the possible sources of discrepancies, and that the results provide a valid comparison of fuel and additive behavior in a representative group of filter-separators.



HORIZONTAL CONFIGURATION

VERTICAL SIDE-BY SIDE CONFIGURATION

VERTICAL SHROUDED ELEMENT CONFIGURATION

VERTICAL SUSPENDED CONFIGURATION

FIGURE 7. FILTER-SEPARATOR CONFIGURATIONS

B. Test Procedure and Rating Methods

The basic test sequence used in the single-element filter efficiency tests consisted of the following:

(1) The element pressure drop and water-separating characteristics were checked on clean additive-free fuel at flow rates up to 150% rated capacity, injecting 0.5% water into the influent fuel stream. This preliminary check served to weed out defective elements.*

(2) The additive was blended into the fuel by circulating through the bypass system.

(3) The filter efficiency test was run, injecting the desired amounts of water and/or test dust.

(4) The used filter was rechecked for pressure drop and water separation at various flow rates.**

Three different types of solid contaminants were used in this program:

(1) Standard coarse A/C test dust

(2) Red iron oxide (Fe_2O_3), Fisher I-116

(3) Black iron oxide (Fe_3O_4), Chemical Commerce No. 105

The particle size distributions of these materials are as required in various filter-separator specifications. The red iron oxide is considerably finer than the other two contaminants; most of the red iron oxide is below 1 micron, whereas the other contaminants range up to 100 or 200 microns.

The major portion of the program was based on two-hour filter efficiency tests with continuous injection of 0.5% water and 272 mg/gal of A/C

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*Very few defective elements were encountered except early in the program, when a high percentage of rejects was found in the elements of one manufacturer. Subsequent lots of these elements were satisfactory.

**The used filter was checked at rated flow and at higher or lower flow, depending on whether the filter was functioning satisfactorily at the end of the test. Within the limits of flow variation possible in the system (from 10 to 40 gpm) no changes were ever effected in the final filter performance.

dust into the influent fuel stream. This is one of the test sequences specified in MIL-F-26678A (USAF) and in earlier filter-separator specifications. However, it should be emphasized that this program was not concerned with rating filters according to any given specification; the procedures and rating levels of the filter-separator specifications merely served as a convenient basis for comparing fuels and additives. Along this line, it may be noted that the maximum solids permitted in the effluent by MIL-F-26678A (USAF), 0.7 mg/liter, was used as a go-no-go rating basis in the entire program. The situation on water content of the effluent was somewhat more complicated, as will be discussed later.

Samples of the effluent stream were taken at 0, 60, and 120 minutes. The initial sample represented the effluent stream after conditions had stabilized (about two minutes after starting to inject the contaminants into the influent). These samples were analyzed for solids content (0.8-micron Millipore filter) and for water by the Karl Fischer method. Samples of the clean fuel before test, with and without additive, were drawn for determining interfacial tension, which was run by the standard ASTM method with a platinum ring. A sample of the clean fuel before test, containing additive, was drawn for determination of water content after saturation (equilibrium dissolved water content) by the Karl Fischer method. The interfacial tension and water-saturation determinations were discontinued after sufficient data had been accumulated.

Readings on the light meter in the effluent stream (or visual ratings in earliest tests) were recorded every 15 minutes. The light meter reading was 35-36 mv with clean fuel before the start of the test, either with or without additive. The presence of either free water or appreciable solids in the effluent caused a sharp drop of the light meter readings.

The pressure drop across the test filter was recorded every 15 minutes, and the element pressure drop was found by deducting a predetermined correction factor for the housing and fittings. Only the element pressure drops are considered in this report. Because of equipment limitations, element pressure drops of more than 35-40" Hg could not be determined. In tests where severe filter plugging was observed, the test was usually shut down when the pressure drop reached this level, in some cases the manometer was shut off from the system in order to complete the last few minutes of the test period.

The tests with red iron oxide were conducted at an injection rate of 286 mg/gallon, with a test duration of 70 minutes. This corresponds to a total solids loading on the element of 20 times the gpm rating of the element. Effluent samples were taken at 0, 30, and 70 minutes. In a few instances tests were continued to 120 minutes, but all ratings were based on the 70 minute period. Dry-fuel tests with red iron oxide were conducted with direct injection of the oxide through the same system used in feeding the A/C dust. In the wet-fuel tests on red iron oxide, 0.5% water was injected continuously, and the iron oxide was injected in the form of a slurry consisting of equal volumes of fuel and water loaded with 0.75 lb of iron oxide per gallon of fuel-water mixture. Slurry of these proportions has been standard in Navy filter-separator testing for some years, and is being used in the new DOD filter-separator specification. Attempts to mix such a slurry based on JP-4 fuel in a Waring blender showed that the slurry was unstable, settling out a clean aqueous phase in 10 to 20 minutes. By replacing 25% of the JP-4 with Bayol D, giving a fuel viscosity about equal to that of kerosene, the slurry stability was increased to about 7 hours. This formula was used in all single-element tests on red iron oxide plus water, recirculating the mixture with an ordinary rotary pump to form the slurry and then injecting it into the filter-separator test loop in exactly the same way as was done for dry dust.

Single-element tests with the black iron oxide were performed with dry fuel only. The oxide was added in the proportion of 286 mg/gal for a test period of 210 minutes, corresponding to a solids loading (in grams) of 60 times the gpm rating of the filter element.

C. Results and Discussion

1 Light Meter Ratings

Before proceeding with a discussion of the experimental results, it is necessary to consider the interrelationship of effluent solids content, water content, and clarity or light meter reading.

It was noted that in the tests with A/C dust a solids content of more than 0.7 mg/liter in the effluent invariably caused visible clouding and light meter readings ranging from 0 to 22 mv (clean fuel gives 35-36 mv). Similarly, effluents having water contents far in excess of their respective saturation values invariably gave clouding and low light meter readings. However, the converse is not true. Many runs showed very definite clouding, but neither high solids nor water contents above the saturation value. Examples of such individual data points are as follows:

Test Filter	Additive	Test Time, min	Solids, mg/liter	Water, ppm	Water Satn, ppm	Light Meter, mv
I	A	120	0.2	58	91	32
	K	120	0.4	69	99	25
	L	120	0.1	67	154	20
II	C	0	0.1	21	89	Cloudy (5 min)

Test Filter	Additive	Test Time, min	Solids, mg/liter	Water, ppm	Water Satn, ppm	Light Meter, mv
III	E	120	0.2	28	111	30
	B	120	0.0	59	104	24
	B	120	0.0	104	134	26
IV	A	120	0.6	56	86	9
	B	120	0.0	25	79	28
	D	120	0.3	52	117	27
	F	120	0.1	81	121	28

Thus, it can be seen that solids and water determinations alone did not show whether the filter-separator was giving clear effluent. In these tests many of the water contents were far below the equilibrium saturation value and the solids contents were low, yet the effluents were cloudy and the light meter readings showed definite decreases from the initial values of 35-36 mv. It appears probable that water saturation of the fuel is not attained within the relatively short residence time of the fuel between water injection and water separation.* Then, in the event of substandard filter-separator performance, the effluent may consist of free water suspended in undersaturated fuel, the total water content being below the corresponding saturation value. If this is the case, then effluent clarity is a more important criterion than total water content, effluent clouding is a direct indication of the passage of free water, which presumably would also pass the element if the fuel were water-saturated. Since the latter condition may well prevail in field operation, it appears that the filter-separator should be required to remove all <u>free</u> water at any and all conditions of initial saturation of the fuel, and thus give clear effluent. Although our data are not sufficiently detailed to resolve this question, the evidence appears firm enough to warrant the use of effluent clarity rather than water content as the primary rating for the tests in this program

A further justification for using effluent clarity as the principal criterion of performance in this program was the difficulty encountered

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*This phenomenon has been noted by others engaged in filter-separator testing. The probabilities of obtaining saturation are, of course, influenced by the initial water content of the fuel, as well as by the degree of agitation and the time of contact. It is to be expected that in winter operation the fuel will be well below saturation as it enters the test section, since it must be warmed from ambient or storage temperature to the test temperature of 70-90°F. It is worthy of note that all of the data in the preceding table were taken from tests run in the period from mid-November to mid-January.

with the Karl Fischer analysis and in establishing reliable water saturation values. This question is discussed in more detail in the following section.

Before accepting the light meter readings as the primary criterion of filter-separator performance, an analysis was made of some 149 data points in tests in which A/C dust and water were injected. Defining as satisfactory a light meter reading of 35 or higher, solids 0.7 mg/liter or below, and water content not more than 5 ppm above the saturation value, the 149 data points are distributed as follows:

Meter OK, solids and water OK	90
Meter bad, solids and/or water bad	34
Total points of agreement	124
Meter bad, solids and water OK	22
Meter OK, solids and/or water bad	3
Total points of disagreement	25

Of the three cases in which the meter readings did not predict the excessive solids or water found by analysis, one was explainable on the basis of lack of precision of the analytical data (water content by Karl Fischer was 9 ppm above the saturation value, which may not be significant), and the other two were zero-minute samples in which the discrepancy was real but was caused by rapidly changing effluent quality and the slight time lag between meter reading and sampling. Thus, it is believed that the meter is entirely reliable in detecting effluent contamination, i.e., no passage of excessive solids or free water can occur without a corresponding drop of the light meter reading.

The analysis of the 22 cases of "meter bad, solids and water OK" is considerably more complex, and will not be discussed in detail here. The analysis indicated the following.

(1) Solids in the range of 0.4-0.7 mg/liter (the upper end of the "acceptable" range) can affect the meter readings. Some 27% of the "meter bad, solids and water OK" cases were in the 0.4-0.7 range of solids.

(2) Entrained air may have caused a few cases of meter deflection without corresponding contamination. Very little difficulty was encountered with air entrainment in the facility, and when it did occur it usually could be identified as such.

(3) It is possible that liquid contaminants, immiscible with the fuel, can be derived from additive-fuel-water

interaction or from the elements themselves. Such contaminants could well be undetectable by the standard solids and water analytical methods. This source of discrepancy between meter readings and analytical data was suspected, especially in the case of one additive. However, its occurrence was random, and could not be pinpointed. It is felt that if such interpretation is correct, the meter readings are entirely valid criteria of failure.

(4) The possibility of undersaturated fuel containing free water has been discussed previously. It is believed that this phenomenon accounts for most of the cases of discrepancies between meter readings and analytical data, and that the meter readings are the more valid criteria.

The usefulness of the light meter in providing a continuous monitoring check on effluent quality may be illustrated by the data from a test on JP-4 fuel containing Additive H, in Test Filter IV:

Minutes	Clarity	Light Meter	Water, ppm Sample	Water, ppm Satn	Solids, mg/liter
0	Clear	35	52	104	.
15	Clear	33	--		--
30	Hazy	32	--		--
45	Cloudy	30	--		--
60	Cloudy	25	95		3.2
75	Cloudy	26	--		--
90	Cloudy	26	--		--
105	Cloudy	26	--		--
120	Cloudy	26	110		3.2

It appears that the 15-minute drop of the meter reading to 33 is significant in indicating the beginning of effluent contamination. Data from other tests have indicated that a two-point drop from the "clean-fuel" reading of 35-36 indicates slight contamination, and is almost invariably followed by further decrease of meter reading and the appearance of gross contamination.

In view of the reliability and operational advantages of the light meter, the readings were used as one of the primary criteria of performance in the filter-separator tests.

2. Water Analyses

Although it does not appear pertinent to discuss here the many difficulties encountered with water analyses, some mention should be made of attempts that were made to establish reliable water saturation values.

Using a standard saturation procedure (storage for 24 hours at 73°F with water/fuel = 0.31) on samples of fuel-additive blends withdrawn from the test system, poor reproducibility of results was obtained. For example, using Additive X at maximum concentration in Gulf Coast JP-4, values of 129, 120, 103, 104, and 85 ppm were obtained for the saturation water contents. Since the samples were obtained from different filter tests, the spread of results is not, strictly speaking, a measure of the repeatability of the water-saturation determination. One direct study of repeatability was performed on a different additive (H) in the same fuel, using a single batch of fuel-additive blend and saturating individual samples by the standard procedure and with varying storage times and water-fuel ratios. The eight determinations showed no significant effect of saturation variables; the average of the determinations was 88 ppm, with a standard deviation of 6 ppm and maximum deviation of 9 ppm. Thus, the uncertainty in the water-saturation values was considerably more than the 5 ppm used as a criterion in filter-separator performance ratings (requirement that effluent water content be no more than 5 ppm above the saturation value).

Some studies were made of another method of saturation, in which the fuel is shaken with water, settled briefly, and sampled by withdrawal through a Millipore filter disc. Apart from practical difficulties caused by slow withdrawal rates, the method was hampered by the formation of lacy emulsion or scum, which introduced uncertainties as to the amount of additive adsorbed at the interface. It was found that water saturation values determined by this method were usually 50 to 65% of those determined by static saturation.

It is believed that most of the difficulty in obtaining reliable water-saturation values was occasioned by the method of water analysis. Much of the uncertainty in Karl Fischer water determinations on additive-containing fuels stems from a lack of knowledge of the behavior of the additives in the Karl Fischer titration. The corrosion inhibitors are probably present in amounts above their respective critical micelle concentrations, this has been demonstrated for one corrosion inhibitor in this group by Perel and Reifenberg.* It is considered that the water "dissolved" in a fuel containing such an additive is held at least partly in the interior of the additive micelles. It appears somewhat doubtful whether such water will be determined quantitatively in the Karl Fischer titration. Further uncertainties are introduced by the presence of other contaminants in the fuel,

*Perel, J. M. and Reifenberg, G. H., "Research and Development on the Surface Active Behavior of Rust Inhibitor 'Santolene C' in JP-5 Jet Fuel.' Material Lab., N. Y. Naval Shipyard, Lab. Project 5319-20, Final Report NS 075-001, April 25, 1958.

e g., materials dissolved from the filter elements. In the case of iron oxide dusts, there appears to be a definite possibility of interference with the Karl Fischer titration.

Although all of the obvious sources of error in the Karl Fischer titration were corrected and great care was observed in standardizing the procedure, we were not able to approach the ±1.25 ppm accuracy which is necessary if water contents relative to saturation value are to be accepted as a primary criterion of filter-separator performance. It will be noted that errors in the Karl Fischer determination affect both the saturation value and the water content found for the effluent, so that it is necessary to have the ±1.25 ppm accuracy to guarantee the 5 ppm spread cited in filter-separator specifications as the allowable excess of effluent water content above the saturation value.

Some work was done in attempts to improve techniques in handling the effluent samples drawn from the rig. The normal procedure used in our program is more or less standard for such work: Dried glass bottles with plastic-lined caps are used; the bottles and any glassware used in transfer are rinsed twice with the test fuel before use. Since opinions have been expressed that this rinsing is not sufficient to equilibrate the glass surfaces with respect to the water content of the fuel, the use of polyethylene bottles was investigated briefly. It was concluded that nonequilibration, if a factor at all, was an insignificant part of the deviations being encountered.

Although the water analyses and the water saturation values in the later stages of the program were improved by general improvement of techniques, they are still not considered as sufficiently reliable as a primary standard in rating the filter-separator tests.

3. Test Results Using A/C Dust and Water in Gulf Coast JP-4 Fuel

In view of the extremely large volume of data generated in this program, the results are presented only in the form of a summary (Table 3). It will be noted from Table 3 that all of the tests on additive-free fuel (Test Filters I - IV) showed satisfactory performance. Test Filter V was not checked on additive free fuel, since it had demonstrated satisfactory performance on some of the additives.

Test Filter I was in general characterized by high element pressure drop in several of the tests exceeding the limit of 3.4" Hg. The tests on three additives (G H, and O) were terminated early because of excessive pressure drop. The excessive pressure drop for Additive G was not typical of its tests in other test filters. In the case of Additive O, no comparative data are available; this additive was included for a single filter-separator run simply as a bad-performance baseline for other small-scale tests described later in this report. In the case of Additive H, the plugging behavior

TABLE 3. SUMMARY OF FILTER EFFICIENCY TEST RESULTS WITH A/C DUST AND WATER

Test Filter I
Gulf Coast JP-4 fuel

Additive[a]	Maximum Value for Test: ΔP, "Hg	Maximum Value for Test: Solids, mg/liter[b]	Maximum Value for Test: Water, ppm[b]	Water Saturation, ppm at 73° F	Minimum Light Meter Reading, mv	Period of Clouding, min
None	21	0.5 (120)	40 (120)	96	33	None
A	29	0.2 (120)	74 (60)	91	30	60-120
B	20	0.2 (0)	64 (60)	82	33	None
C	34	0.5 (60)	124 (0)	105	2	0-115[c]
C	25	0.4 (0)	107 (60)	141	28	6-13
D	19	0.2 (0)	88 (120)	136	34	None
E	27	0.3 (120)	99 (120)	(d)	35	None
F	16	0.0	115 (60)	183	34	None
G	>34	1.6 (90)	353 (90)	(d)	2	0-90[e]
H	>34	0.6 (16)	96 (0)	99	24	1-16[e]
H[f]	7	None added	80 (120)	89	34	None
J	>34	0.5 (60)	160 (60)	112	20	15-120
K	22	0.4 (120)	78 (0)	99	25	30-120
L	21	0.2 (60)	73 (60)	(d)	20	30-120
N	18	0.0	86 (60)	120	34	None
O	>34	3.1 (14)	--	--	0	0-14[e]

(a) Maximum allowable concentration per MIL-I-25017
(b) Figures in parentheses represent minutes at which "maximum" sample was taken.
(c) Test terminated at 115 minutes; several fuel pump failures experienced throughout test.
(d) Saturation sample cloudy when drawn.
(e) Test terminated prior to completion of full 120-minute period.
(f) Test conducted without the injection of test dust contaminants.

TABLE 3. SUMMARY OF FILTER EFFICIENCY TEST RESULTS WITH A/C DUST AND WATER (Cont'd)

Test Filter II
Gulf Coast JP-4 fuel

Additive(a)	ΔP, "Hg	Maximum Value for Test: Solids, mg/liter(b)	Maximum Value for Test: Water, ppm(b)	Water Saturation, ppm at 73°F	Period of Clouding, min
None	3.6	0.5 (0)	126 (0)	100	None
A	3.4	0.2 (0)	147 (0)	127	None
B	2.9	0.7 (120)	166 (120)	(c)	None
C	6.1	5.9 (0)	587 (0)	(c)	0-25
C	3.6	0.1 (120)	42 (120)	89	5-15
D	3.6	0.2 (60)	234 (0)	226	None
E	4.4	0.2 (0)	121 (0)	[illegible]5	None
F	4.5	0.2 (60)	110 (0)	(c)	None
G	5.6	0.1 (120)	50 (120)	(c)	None
H	40.6	2.9 (60)	127 (60)	77	15-90(d)
H	[illegible]39.1	2.1 (60)	(e)	81	15-75(f)
I	5.8	0.1 (120)	144 (120)	(c)	30-120
J	4.4	0.1 (120)	248 (120)	70	15-120
K	4.7	0.2 (60)	366 (120)	(c)	15-120
L	[illegible].6	0.2 (120)	278 (120)	(c)	30-120
N	3.2	0.2 (60)	74 (120)	104	None

(a) Maximum allowable concentration per MIL-I-25017.
(b) Figures in parentheses represent minutes at which "maximum" sample was taken.
(c) Saturation sample cloudy when drawn.
(d) Test terminated at 90 minutes.
(e) Sample lost in handling.
(f) Test terminated at 75 minutes.

TABLE 3. SUMMARY OF FILTER EFFICIENCY TEST RESULTS
WITH A/C DUST AND WATER (Cont'd)

Test Filter III
Gulf Coast JP-4 fuel

Additive[a]	Maximum Value for Test: ΔP, "Hg	Maximum Value for Test: Solids, mg/liter[b]	Maximum Value for Test: Water, ppm[b]	Water Saturation, ppm at 73°F	Minimum Light Meter Reading, mv	Period of Clouding, min
None	3.0	0.1 (0)	59 (0)	103	--	None
None	1.5	0.2 (0)	101 (60)	102	31[c]	None
A	0.8	1.8 (120)	359 (120)	(d)	1[c]	0-120
B	0.0	0.3 (0)	65 (60)	104	24[c]	45-120
B	1.2	0.2 (60)	109 (60)	134	26[c]	45-120
C	4.8	14.9 (0)	197 (0)	106	--	0-120
D	2.0	0.4 (120)	105 (120)	134	13[c]	15-120
E	6.5	0.2 (120)	32 (60)	(d)	29[c]	75-120
E	8.1	0.4 (120)	78 (60)	75	35	None
F	1.7	0.9 (0)	102 (120)	118	22[c]	30-120
G	18.5	5.7 (120)	206 (120)	(d)	0[c]	7-120
H	34.5	13.7 (45)	185 (45)	(d)	0[c]	0-45[e]
J	1.7	8.4 (60)	126 (120)	92	--	0-120
K	1.5	2.8 (120)	159 (120)	108	1[c]	5-120
L	3.7	5.6 (120)	18,650 (60)	(d)	0[c]	0-120
N	2.7	0.0	109 (60)	83	26	30-120

(a) Maximum allowable concentration per MIL-I-25017.
(b) Figures in parentheses represent minutes at which "maximum" sample was taken.
(c) These light meter readings are only approximate, since the constant-voltage transformer was not in service.
(d) Saturation sample cloudy when drawn.
(e) Test terminated at 45 minutes.

TABLE 3. SUMMARY OF FILTER EFFICIENCY TEST RESULTS WITH A/C DUST AND WATER (Cont'd)

Test Filter IV
Gulf Coast JP-4 fuel

Additive(a)	Maximum Value for Test: ΔP, "Hg	Maximum Value for Test: Solids, mg/liter(b)	Maximum Value for Test: Water, ppm(b)	Water Saturation, ppm at 73°F	Minimum Light Meter Reading, mv	Period of Clouding, min
None	3.0	0.1 (0)	77 (120)	75	36	None
A	2.2	0.6 (120)	56 (120)	85	9	0-120
B	1.5	0.1 (0)	25 (120)	79	28	45-120
C	2.5	2.6 (0)	83 (0)	122	6	0-30, 90-120
D	2.7	0.4 (0)	58 (60)	(c)	27	45-120
E	0.9	0.0	81 (120)	87	34	None
F	2.0	0.2 (0)	81 (120)	121	28	90-120
G	3.0	0.8 (120)	233 (120)	144	15	15-120
H	5.0	2.0 (60)	180 (120)	132	16	15-120
H	5.0	3.2 (120)	110 (120)	104	25	30-120
J	0.7	2.6 (120)	3,447 (120)	139	0	15-120
K	1.6	1.3 (120)	4,087 (120)	86	0	15-120
L	0.5	3.6 (120)	1,999 (120)	101	0	0-120
N	0.5	0.3 (0)	106 (0)	129	33	None
N	0.0	0.2 (120)	97 (0)	103	34	90-120(d)

(a) Maximum allowable concentration per MIL-I-25017.
(b) Figures in parentheses represent minutes at which "maximum" sample was taken.
(c) Saturation sample cloudy when drawn.
(d) Very slight haze.

TABLE 3. SUMMARY OF FILTER EFFICIENCY TEST RESULTS WITH A/C DUST AND WATER (Cont'd)

Test Filter V
Gulf Coast JP-4 fuel

Additive[a]	ΔP, "Hg	Maximum Value for Test: Solids, mg/liter[b]	Maximum Value for Test: Water, ppm[b]	Water Saturation, ppm at 73°F	Period of Clouding, min
A	5	0.0	273 (120)	15	0-120
B	3	0.0	109 (120)	27	30-120
C	4	0.0	89 (60)	23	15-120
D	5	0.0	--	29	(c)
E	7	0.1 (120)	--	33	None
F	3	0.2 (0)	107 (60)	31	(c)
F	3	0.4 (0)	117 (0)	32	(c)
G	5	0.1 (120)	--	22	0-120
H	>40	0.7 (0)	--	20	0-120
J	3	0.0	--	9	0-120
K	3	0.0	--	11	15-120
L	3	0.3 (0)	--	11	15-120
N	2	0.0	--	33	None

(a) Maximum allowable concentration per MIL-I-25017.
(b) Figures in parentheses represent time at which "maximum" sample was taken.
(c) Slight haze observed which may have been caused by entrained air.

when run with A/C dust and water was typical for all of the element types, four out of the five showing excessive pressure drops. This additive was also run in Test Filter I with the standard 0.5% water but without test dust. Very little pressure drop was obtained, indicating that the plugging behavior of Additive H is occasioned by additive-dust interaction.

The results with Test Filter II included duplicate tests on three additives, all of which showed good repeatability. The two tests on Additive C both showed a cloud-clear sequence. In the one test the cloud appeared at once, so that the zero-minute sample showed excessive water and solids, in the other test, the cloud was delayed until after five minutes had passed, so that the zero-minute sample did not detect the contamination present later. Both tests on Additive H showed the excessive plugging typical of this additive, and were in excellent agreement on solids content and period of clogging. Incidentally, Additive H was the only "plugger" in Test Filter II. The two tests on Additive J gave almost identical check results with respect to pressure drop, solids, and period of clouding, and both tests showed excessive water content to be the source of the clouding. The results on Test Filter II were obtained before the installation of the light meter.

The results with Test Filter III showed that most of the additives interfered seriously with its functioning, only Additives B and E gave good or marginal results. In the initial tests on these additives, the effluents showed so-   haze during the last half of each test, although no free water or excessive solids were detected by analysis. As discussed previously, this behavior is attributed to "undersaturation" of the fuel. Additive E in a repeat test showed satisfactory performance

In the case of Test Filter IV the only two additives giving satisfactory or marginal ratings were E and N. This test filter was the only unit which handled Additive H without excessive pressure drop, however, in both tests on this additive, the solids contents of the effluents were excessive.

Test Filter V was similar to IV in that the best results were obtained with Additives E and N. The interpretation of the data on Additives D and F in Test Filter V was complicated by the presence of entrained air, since this unit had an inadequate air-bleed system.

One point requiring some discussion is the cause of the effluent clouding observed with Additive C. This additive differs from the others in that effluent clouding often occurred most markedly in the first few minutes of the test, sometimes with marked improvement as the test progressed. Also, the tests on this additive had shown a marked tendency to give cloudy effluents along with low water and solids contents. As discussed previously, this could indicate nonequilibration and "undersaturation" of the effluent. However, it appears that for this particular additive the hypothesis is not applicable, in view of the marked improvement often observed as the test progresses. A summary of the tests on this additive is given in Table 4. It will be noted that in six out of the seven tests the clarity and/or water content of the effluent improved as the test progressed. The water contents observed at 60 and 120 minutes were at or below the nominal saturation value of 123 ppm in all tests except a single test in Test Filter II, and the repeat test in this filter gave low water contents throughout. Although the reasons for the erratic behavior of this additive are not at all obvious, it is suspected that a reaction between the additive and water and/or fuel impurities is responsible. Statements have been made that this additive reacts quite differently with different fuels. No data are available from this program which shed any light on such behavior.

To develop some information on the effect of additive concentration, five of the corrosion inhibitors were checked at minimum allowable concentration (per MIL-I-25017) in Test Filter I. The inhibitors were chosen as representative of those showing severe effects on filter-separator performance when used at maximum concentration. The comparative results at the two concentrations are shown in Table 5. It will be observed that for Additives J and K the "minimum" results were as bad as the "maximum." However, for these additives the maximum and minimum concentrations are close together, and this is reflected in the relatively small difference of interfacial tension between the maximum and minimum concentrations. Additives C, G, and H have minimum allowable concentrations which are 26 to 40% of the corresponding maximums; in the filter tests on these additives at minimum concentration the results were unquestionably satisfactory. It will be noted that the corresponding interfacial tensions at minimum concentrations of these three additives are all close to that of the additive-free fuel (about 40 dynes/cm). From curves of interfacial tension vs concentration on one of these additives, it was evident that the critical micelle concentration fell between the maximum and minimum. It appears probable that any additive conforming to this relationship will show major differences in the effects of maximum and minimum concentration on filter performance.

The improved results on three of the inhibitors at minimum concentration raises the question of whether the major part of this entire program, which is based on maximum concentrations, is at all realistic. In fuel procurements during the period when the use of corrosion inhibitors was required, the minimum concentration was most frequently used, the maximum being used only to meet some definite need (e.g., pipeline protection). This question was discussed at some length with personnel at ASD and others. It was generally agreed that the specification limits, which in some cases allow a wide spread between minimum and maximum concentration, may be undesirable, however, so long as these limits exist, filter-separator test work is obliged to take account of additive performance at maximum concentration. Therefore, all further single-element test work was performed at maximum additive concentrations, and all subsequent discussion is on this basis.

TABLE 4 FILTER EFFICIENCY TEST RESULTS ON ADDITIVE C

Gulf Coast JP-4 fuel
A/C test dust and water
Additive at maximum concentration

Test Filter	Test Time, min	Solids, mg/liter	Water, ppm(a)	Light Meter Reading	Effluent Clarity	Comments
I	0	0.0	124	2	Cloudy	
	60	0.5	71	30	Slight haze	
	115	0.1	61	32	Slight haze	
	0	0.4	51	35	Clear	Cloudy 6-13 min
	60	0.1	107	35	Clear	
	120	0.2	80	34	Clear	
II	0	5.9	587	--	--	Cloudy 0-25 min
	60	0.1	205	--	Clear	
	120	0.0	104	--	Clear	
	0	0.1	21	--	Clear	Cloudy 5-15 min
	60	0.1	33	--	Clear	
	120	0.1	42	--	Clear	
III	0	14.9	197	--	Cloudy	
	60	1.1	124	--	Cloudy	
	120	0.0	115	--	Cloudy	
IV	0	2.6	83	6	Cloudy	Cloudy 0-30 min
	60	0.4	49	33	Clear	
	120	0.1	44	30	Hazy	Hazy 90-120 min
V	0	0.0	73	34	Clear	Cloudy 15-120 min
	60	0.0	39	25	Cloudy	
	120	0.0	36	25	Cloudy	

(a) Nominal saturation value 123 ppm, based on average of several tests.

(a) Nominal saturation value 123 ppm, based on average of several tests.

TABLE 5. FILTER EFFICIENCY TEST RESULTS AT MINIMUM AND MAXIMUM ADDITIVE CONCENTRATIONS

Gulf Coast JP-4 fuel
Test Filter I
A/C test dust and water

Additive	Concentration	IFT, dynes/cm	Maximum Value for Test: ΔP, "Hg	Maximum Value for Test: Solids, mg/liter(a)	Maximum Value for Test: Water, ppm(a)	Minimum Light Meter Reading, mv	Period of Clouding, min
C	Min	35	11	0.0	68 (0)	36	None
	Max	17	34	0.5 (0)	124 (0)	2	0-115(b)
G	Min	37	22	0.0	108 (60)	36	None
	Max	32	>34	1.6 (90)	353 (90)	2	0-90(b)
H	Min	39	33	0.2 (0)	82 (120)	36	None
	Max	29	>34	0.6 (16)	96 (0)	24	1-16(b)
J	Min	19	>34	0.2 (60)	321 (120)	5	0-120
	Max	17	>34	0.5 (60)	160 (60)	20	15-120
K	Min	17	28	0.1 (120)	156 (120)	10	0-120
	Max	8	22	0.4 (120)	78 (0)	25	30-120

(a) Figures in parentheses represent minutes at which "maximum" value was observed.
(b) Test terminated at time shown; effluent cloudy throughout test.

In order to provide a condensed summary of the large volume of test results, it is necessary to make some rather arbitrary definitions of satisfactory performance. Satisfactory solids retention is defined as less than 0.7 mg/liter in the effluent throughout the run. Satisfactory performance on water separation is defined as the absence of any cloud (detected either by the light meter or visually) throughout the run; this is really a double rating, since it may be influenced by solids as well as by water. Water contents of the effluent are not used in the rating, since at best they are far less sensitive and accurate than the light meter and visual ratings. Satisfactory performance on filter plugging is defined as an element ΔP less than 34" Hg in a two-hour test.

Using these definitions, ratings have been assigned to each element-additive combination tested with A/C dust, as shown in Table 6. The over-all percentage of satisfactory ratings is calculated for each element and each inhibitor. The percentage of satisfactory ratings ranged from 93% (Additive E) down to 13% (Additive H). The additive ratings by the different criteria may be compared more readily by the following tabulation showing the number of satisfactory ratings (out of five possible) by each criterion:

	Number of Satisfactory Ratings			
Additive	Solids Retention	Effluent Clouding	Filter Plugging	Total
E	5	4	5	14
N	5	3	5	13
D	5	2	5	12
F	4	2	5	11
B	4	2	5	11
A	4	1	5	10
K	3	0	5	8
L	3	0	5	8
J	3	0	4	7
C	2	0	4	6
G	2	1	4	7
H	1	0	1	2

The comparative ratings of the filters showed a considerable spread by each of the criteria but less spread on over-all ratings. Filter II was the most satisfactory over-all, I and V were rated equal (but on the basis of different criteria), and IV and III followed in that order. It should be noted that the "over-all" ratings should not be taken too literally, since there is no mathematical basis for averaging the three indices into a single rating.

The same order was shown by the ratings of effluent clouding, except that Filter V was considerably less satisfactory than I.

TABLE 6 COMPARATIVE RATINGS OF ADDITIVE EFFECTS AND FILTER PERFORMANCE

Gulf Coast JP-4, A/C test dust and water
Legend: S - Satisfactory
M - Marginal
U - Unsatisfactory

Additive	Filter I (a)	Filter I (b)	Filter I (c)	Filter II (a)	Filter II (b)	Filter II (c)	Filter III (a)	Filter III (b)	Filter III (c)	Filter IV (a)	Filter IV (b)	Filter IV (c)	Filter V (a)	Filter V (b)	Filter V (c)	% Satisfactory
A	S	U	S	S	S	S	U	U	S	S	U	S	S	U	S	67
B	S	S	S	M	S	S	S	U	S	S	U	S	S	U	S	73
C	S	U	M	U	U	S	U	U	S	U	U	S	S	U	S	40
D	S	S	S	S	S	S	S	U	S	S	U	S	S	M	S	80
E	S	S	S	S	S	S	S	M	S	S	S	S	S	S	S	93
F	S	S	S	S	S	S	U	U	S	S	U	S	S	M	S	73
G	U	U	U	S	S	S	U	U	S	U	U	S	S	U	S	47
H	S	U	U	U	U	U	U	U	U	U	U	S	U	U	U	13
J	S	U	U	S	U	S	U	U	S	U	U	S	S	U	S	47
K	S	U	S	S	U	S	U	U	S	U	U	S	S	U	S	53
L	S	U	S	S	U	S	U	U	S	U	U	S	S	U	S	53
N	S	S	S	S	S	S	S	U	S	S	M	S	S	S	S	87
% Satisfactory	92	42	67	75	58	92	33	0	92	50	8	100	92	17	92	
% Satisfactory Over-all	67			75			42			53			67			

(a) Solids retention.
(b) Effluent clouding.
(c) Filter plugging

Ratings of solids removal show, in general, an inverse relationship: Filter I, which was very effective in solids removal, also showed by far the worst plugging behavior. Rating the elements on a lower ΔP value would have emphasized this behavior. Although V was rated as high as I on solids removal, V did not show the plugging which might have been expected. Major differences in the dirt-holding capacity of these filters are not too surprising, in view of the wide differences in element design and arrangement.

Arranging the additives according to the number of satisfactory performances on effluent clarity, the following order is observed (where half ratings are used to indicate marginal test results):

E	4.5
N	3.5
D	2.5
F	2.5
B	2
A	1
G	1
C	0
H	0
J	0
K	0
L	0

Thus it is seen that only four out of the twelve corrosion inhibitors gave satisfactory effluent clarity in more than two of the test filters. None of the additives exhibited harmless effects in all five filter units, although Additive E was given only one "marginal" rating for clouding.

It is noted that the performance of most additives in effluent clouding shows a general relationship with interfacial tension. The data on the following page illustrate the interrelationship between additive performance and the interfacial tension of the fuel after initial blending with additive, after running for two hours in a standard filter efficiency test, and after thorough extraction with water in a laboratory apparatus.* The data shown in the following tabulation for the "as-blended" and "after-test" samples are averages for a number of filter-separator runs. Although some deviations were noted among the IFT values for a given additive in different runs, the deviations were not sufficient to alter the basic order shown in the tabulation, and there was no significant relationship between filter type and IFT "after-test" value. It will be noted that the general relationship between performance and IFT is

*200 ml samples of fuel-additive blends were extracted by dropwise percolation of 4 liters of water through the fuel.

marked by some notable exceptions. Additive N is completely out of line in the "as-blended" IFT ratings, the low value of 21 suggesting poor perform ance rather than the relatively good performance observed. Interestingly,

Additive	Interfacial Tension, dynes/cm As Blended	After Test	After Extraction	Number of Satisfactory Effluent Ratings
E	38	40	41	4.5
N	21	25	40	3.5
D	29	37	36	2.5
F	33	36	36	2.5
B	23	24	44	2
A	28	33	35	1
G	27	33	3[illegible]	1
C	18	17	5	0
H	31	35	36	0
J	16	16	19	0
K	11	14	17	0
L	15	18	16	0

this additive after thorough extraction of the fuel-additive blend with water gives an IFT approaching that of clean fuel. The same sort of behavior upon extraction was shown by Additive B, indicating that moderate amounts of water are insufficient to remove these additives, but that large amounts of water probably cause complete extraction. Although in the most general sense this statement can apply to any additive, it is specific for Additives B and N within the range of extraction conditions studied here, which included water-fuel ratios from approximately 0.08 (in the filter tests) to 20 (in the laboratory extraction).

Referring again to the preceding tabulation, it will be noted that Additive H is out of line in the opposite sense: Its high values of IFT are not characteristic of the other poor-performance inhibitors.

Examining the values of IFT after thorough extraction, one may generalize that any additive which after thorough extraction shows an IFT below 20 (or in fact below 30) is apt to give very poor coalescer performance. However, the converse is not true: A high IFT after extraction does not guarantee good performance, as is illustrated by the data on Additive H.

The general relationship between IFT values and effect on coalescense was illustrated further by the data presented previously on five additives at maximum and minimum concentrations.

4. Effect of High-Aromatics Fuel

The special high-aromatics (24%) JP-4 fuel prepared by Ashland was run with each of the corrosion inhibitors in Test Filter I, and with three other test filters using Additive B only. The results of these tests are listed in Table 7. A comparison of these data with those obtained on the Gulf Coast JP-4 (which contained 12% aromatics) shows that the two fuels gave very similar results in effluent clouding and solids retention, but that the high-aromatics fuel was significantly worse in filter plugging. This comparison is illustrated in Table 8.

5. Test Results Using Iron Oxide Dusts

The data obtained using red iron oxide (wet and dry) and black iron oxide (dry) are shown in Table 9. These data are not as extensive as those on the A/C dust. The majority of the corrosion inhibitors were evaluated with dry red iron oxide in Test Filter II, and selected inhibitors were evaluated with wet and dry red iron oxide in each of the test filters. The tests with black iron oxide were confined to single tests with Additive B in Test Filters I and II.

It will be noted that the light meter was quite sensitive to the presence of iron oxide in the effluent, in some cases detecting concentrations which were not evident visually (e.g., in the test on Additive K on dry red iron oxide in Test Filter III).

For ease of comparison, the results are reduced to pass-fail ratings in Table 10. Only the solids retention ratings are shown, as these appear to be the most significant. Incidentally, no effluent clouding due to water was noted in any of the failing tests on wet red iron oxide (slurry). In all instances where an effluent cloud was noted, the reddish color of the oxide predominated, and no excess water could be identified visually. Karl Fischer determinations on a few of these samples gave extremely variable results, and it was concluded that the presence of iron oxide was interfering with the titration.

Considering first the tests with dry red iron oxide in Test Filter II, it will be noted that satisfactory performance was obtained with additive-free fuel and with Additives B, E, and H. It will be recalled that Additive H in tests with A/C dust plus water gave excessive plugging in most of the filters, including II. With dry red iron oxide the unsatisfactory tests in Test Filter II included Additives C, D, F, and N; the last three of these additives had been satisfactory with A/C dust and water in this filter. The failure on Additive C with red iron oxide was very pronounced, and it was noted that the presence of this additive apparently promoted dispersion of the red iron oxide in the dust mixing system. The red iron oxide, although very fine, has a pronounced tendency toward aggregation of the particles,

TABLE 7. FILTER EFFICIENCY TESTS WITH HIGH-AROMATICS FUEL

A/C test dust and water

Additive(a)	ΔP, "Hg	Maximum Value for Test: Solids, mg/liter(b)	Maximum Value for Test: Water, ppm(b)	Water Saturation Value, ppm at 73°F	Maximum Light Meter Reading, mv	Period of Clouding, min
			Test Filter I			
None	15	0.0	115 (60)	146	36	None
A	>34	0.1 (60)	129 (60)	105	22	15-65(c)
B	>34	2.4 (0)	104 (0)	137	35	None(c)
C	>34	1.2 (0)	379 (0)	129	3	0-25(c)
D	15	0.0	104 (60)	153	36	None
E	30	0.1 (120)	109 (60)	115	36	None
F	22	0.1 (0)	128 (60)	153	36	None
G	>34	0.4 (30)	100 (30)	145	24	15-30(c)
H	>34	0.5 (22)	187 (22)	110	16	None(d)
J	>34	0.2 (60)	181 (60)	149	11	15-120
K	25	0.1 (120)	142 (120)	140	12	30-120
L	22	0.2 (120)	209 (60)	129	9	30-120
N	14	0.1 (120)	134 (60)	133	36	None
			Test Filter II			
B	3.9	0.1 (60)	91 (120)	117	36	None
			Test Filter III			
B	2.0	0.4 (60)	167 (60)	131	2	15-120
			Test Filter IV			
B	0.5	0.1 (120)	151 (120)	142	22	30-120

(a) Maximum allowable concentration per MIL-I-25017.
(b) Figures in parentheses represent minutes at which "maximum" value was observed.
(c) Test terminated prior to completion of 2-hour run.
(d) Effluent clear up to time of coalescer rupture.

TABLE 8. EFFECT OF FUEL TYPE ON FILTER-SEPARATOR PERFORMANCE

A/C test dust and water

Legend: S = Satisfactory
M = Marginal
U = Unsatisfactory

Additive	Test Filter	Gulf Coast JP-4 (a)	Gulf Coast JP-4 (b)	Gulf Coast JP-4 (c)	High-Aromatics JP-4 (a)	High-Aromatics JP-4 (b)	High-Aromatics JP-4 (c)
A	I	S	U	S	S	U	U
B	I	S	S	S	U	S	U
C	I	S	U	M	U	U	U
D	I	S	S	S	S	S	S
E	I	S	S	S	S	S	S
F	I	S	S	S	S	S	S
G	I	U	U	U	S	U	U
H	I	S	U	U	S	S(d)	U
J	I	S	U	U	S	U	U
K	I	S	U	S	S	U	S
L	I	S	U	S	S	U	S
N	I	S	S	S	S	S	S
B	II	M	S	S	S	S	S
B	III	S	U	S	S	U	S
B	IV	S	U	S	S	U	S
% Satisfactory		87	40	73	87	47	60
% Satisfactory Over-all			67			64	

(a) Solids retention.
(b) Effluent clouding
(c) Filter plugging.
(d) Satisfactory performance up to time of coalescer rupture.

TABLE 9 SUMMARY OF FILTER EFFICIENCY TEST RESULTS WITH IRON OXIDE DUSTS

Gulf Coast JP-4 fuel

Test Filter	Additive[a]	Max Value for Test: ΔP, "Hg	Max Value for Test: Solids, mg/liter[b]	Minimum Light Meter Reading, mv	Period of Clouding, min
		Red Iron Oxide, Dry			
I	None	>34	1.7 (55)	26	(c)
	B	10	0.2 (70)	22 (air)	None
	E	>34	0.4 (55)	32	(c)
II	None	2	0.0	36	None
	B	2	0.2 (0)	36	None
	C	2	15.9 (30)	5	0-30[d]
	D	4	1.3 (70)	31	15-70
	E	1	0.0	36	None
	F	2	1.4 (70)	30	15-70
	H	1	0.2 (70)	33	None
	K	1	0.7 (0)	31	None
	N	1	1.8 (70)	29	0-70
III	None	5	0.0	35	None
	B	0	2.8 (0)	10	0.5[d]
IV	None	5	0.0	29 (air)	None
	H	[illegible]	[illegible].0 (70)	25	At 70
V	B	3	3.3 (15)	10	0-15[d]
		Red Iron Oxide, Wet (Slurry)			
I	None	34	0.1 (70)	34	None
	B	[illegible]	[illegible].4 (0)	24	0-5[d]
II	None	26	[illegible].1 (70)	27	60-70
	None	8	0.1 (30)	34	None
	B	[illegible]	7.6 (0)	12	0-4[d]
	E	10	[illegible].1 (70)	23	30-70
III	None	11	0.1 (70)	35	None
IV	None	17	0.1 (30)	34	None
		Black Iron Oxide, Dry			
I	B	34	0.3 (165)	34	None[d]
II	B	2	0.3 (0)	34	None

(a) Maximum allowable concentration per MIL-I-25017.
(b) Figures in parentheses represent minutes at which 'maximum' sample was taken
(c) Coalescer failure noted at 55 minutes; test terminated immediately.
(d) Test terminated before end of normal period

TABLE 10. COMPARATIVE RATINGS OF ADDITIVE EFFECTS ON FILTER PERFORMANCE WITH IRON OXIDE TEST DUSTS

Gulf Coast JP-4 fuel

Legend: S = Satisfactory
M = Marginal
U = Unsatisfactory

Iron Oxide Test Dust	Additive	Solids Retention Rating with Filter				
		I	II	III	IV	V
Red, dry	None	U[a]	S	S	S	
	B	S	S	U		U
	C		U			
	D		U			
	E	U[a]	S			
	F		U			
	H		S		U	
	K		M			
	N		U			
Red, wet (slurry)	None	S[a]	M	S	S	
	B	U	U			
	E		U			
Black, dry	B	S[a]	S			

(a) Unsatisfactory with respect to filter plugging (pressure drop).

and it appears probable that the relative performance of the various fuel additives with the dry red iron oxide is inversely related to their ability to disperse the aggregates.

In comparing Test Filter II with the other filters on dry red iron oxide, the very limited data indicate that the additives handled successfully by II (B, E, and H) can cause difficulty in other types of filters.

In the tests using wet red iron oxide (slurry) in additive-free fuel, one bad test was obtained with Test Filter II, but the repeat test was satisfactory. Test Filters I, III, and IV handled the additive-free fuel successfully, although relatively high pressure drops were noted (Table 9). In the three instances where additive-containing fuels were run with slurry, failures were noted. Although these data are very limited, they do point out the extremely adverse effect in "slurry" tests of one additive (B) which did not cause difficulty in the dry red iron oxide tests on the same filters (I and II).

The two tests with dry black iron oxide using Additive B showed reasonably good performance, except that in Test Filter I the run had to be terminated at 165 minutes because of excessive pressure drop. The run in Test Filter II was entirely satisfactory. These two runs were made principally to obtain particle count data on effluents with this particular contaminant. However, it was found that the Millipore filters used for the counting contained a considerable amount of the red iron oxide, evidently remaining in the system from previous tests. Since it was difficult to distinguish between the two types of particles in the microscopic examination, it was impossible to obtain a valid count on the black oxide.

IV CRC WATER SEPAROMETER

A Test Equipment

The CRC water separometer is a small-scale rig for comparing fuels and additives as to ease of coalescence of dispersed water. The basic design of the apparatus was worked out at the Naval Research Laboratory*, and the standard rigs have been built by Emcee Electronics, Claymont, Delaware. A photograph of the control panel and coalescing and settling section is shown in Figure 8, and a flow diagram is shown in Figure 9.

In operation of this rig, a fuel-water emulsion, formed by recirculating through a pressure relief valve, is metered through a coalescing section which consists of a pair of small Fiberglas discs, compressed to constant volume, with 1.0 cm^2 effective cross-sectional area. Coalesced water falls out in a small glass settling chamber, and the fuel effluent passes through a light cell (turbidimeter) where any emulsified or suspended water is detected by its effect on light transmittance.

Several modifications of the original apparatus have been made; these have been coordinated by the CRC Water Separometer Panel of the CRC-Aviation Group on Jet Fuel Icing Problems, in order to keep all of the rigs standard. These changes will not be discussed in detail here. However, mention should be made of the problems encountered with fuel cooling; neither the in-line cooler originally furnished with the unit nor the use of an additional cooling coil around the fuel tank proved adequate to maintain the desired 75-85°F range under summer conditions. It was found necessary to operate the equipment in an air-conditioned room.

Mention should also be made of the standardization of the coalescer discs, which was found necessary since the weight of the discs (and hence their density when compressed to a constant volume) has a marked influence on coalescing ability. The discs are now standardized by measurement of air permeability, with pressure-drop limits of 16.5 to 19.5 cm water on the fine discs and 2.0 to 3.2 cm water on the coarse discs, at an air flow of 8 liters/min.

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*Krynitsky, J. A. and Garrett, W. D., "Development of the Water Separometer," NRL Memorandum Report 1105, October 1960 (interim report).

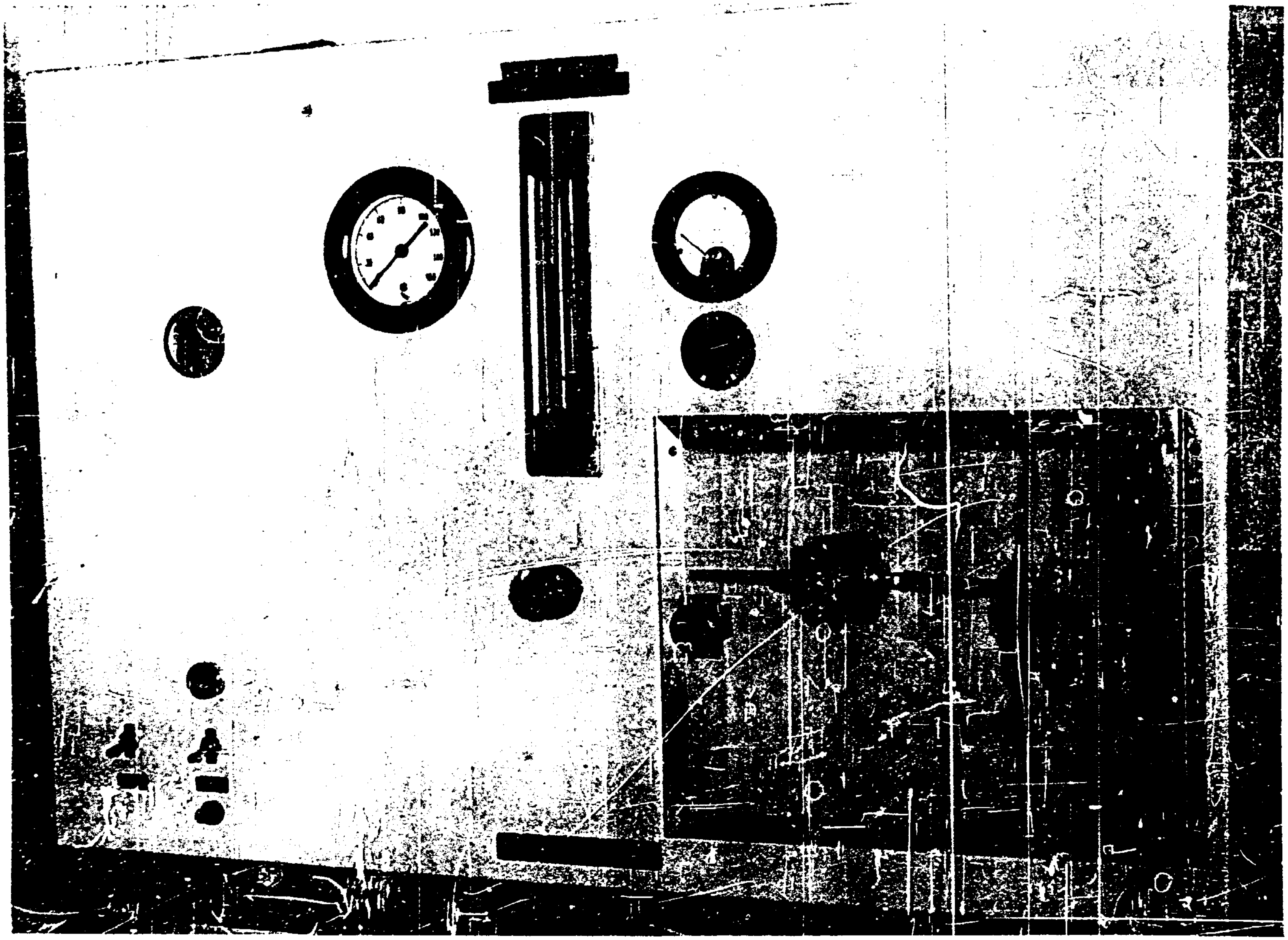

FIGURE 8. CRC WATER SEPAROMETER

FIGURE 8. CRC WATER SEPAROMETER

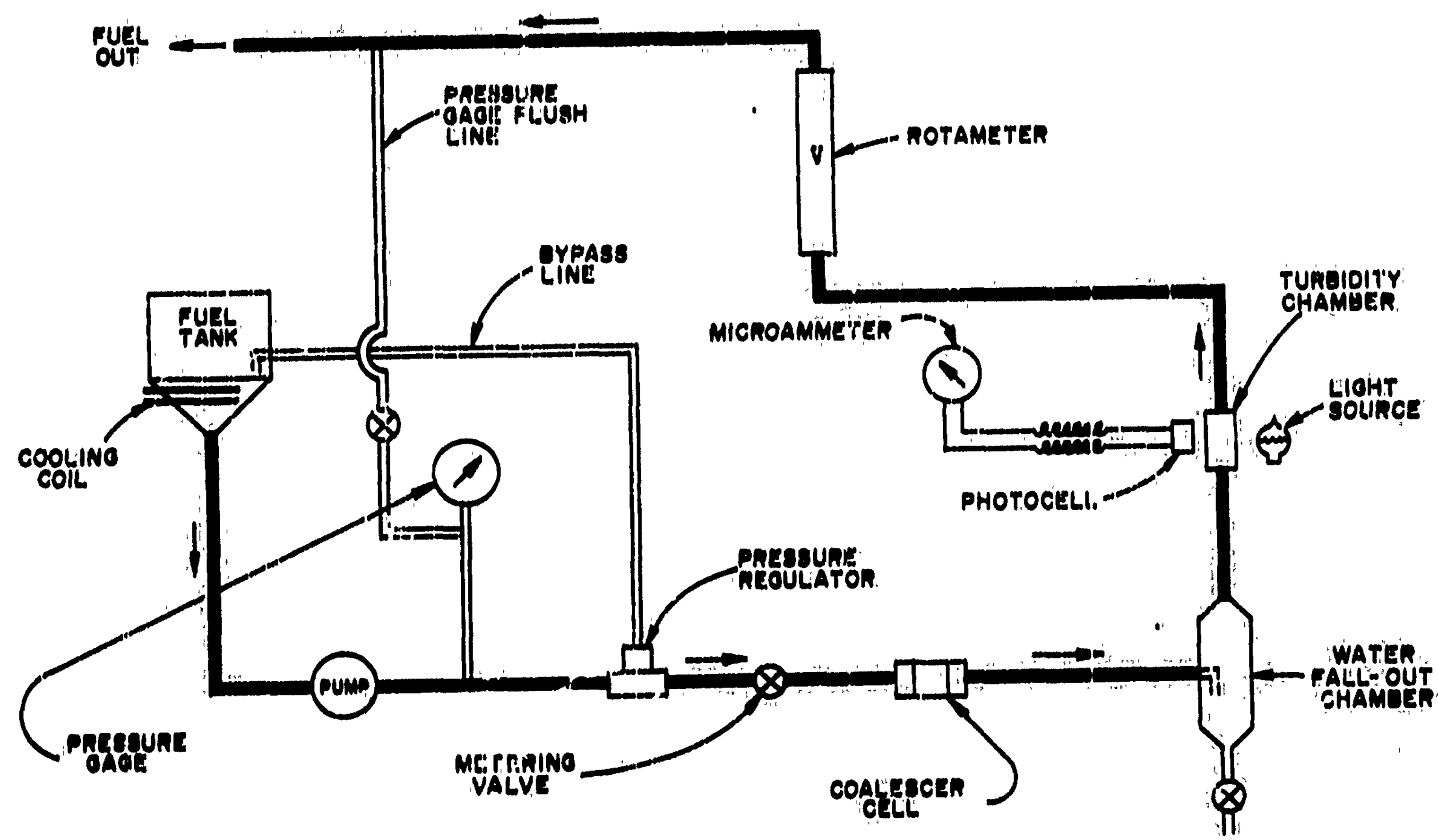

FIGURE 9. FLOW DIAGRAM OF CRC WATER SEPAROMETER

B. Test Procedure

The over-all operating procedure has been outlined by the CRC Panel, and the tests in the SwRI program have followed this outline except for some changes in flushing procedures which will be discussed later. The following is a summary of the standard procedure.

Starting with a clean rig, flushed with Bayol D, new coalescer elements are installed and the entire system is flushed with 250 ml of test fuel. The turbidimeter (light meter) is set to 100 during this period. The relief valve is set to maintain 90 psi pump pressure. Two liters of prefiltered test fuel are poured into the tank, and 1% (20 ml) of distilled water is added while recirculating for five minutes to form the emulsion. This mixture is then metered through the coalescer at a set schedule of increasing flow rates; two schedules have been used, as follows:

Flow Rate ml/min	Minutes Original	Minutes Revised
20	--	10
30	10	7
40	7	5
50	5	4
70	4	3
90	3	3
110	2.5	2.5

Turbidimeter readings are taken at the end of each period and averaged to obtain a comparative rating on the fuel or fuel-additive blend.

In the standard cleanup procedure the system is washed with a total of 1000 ml of 99% isopropanol in four or five portions. After the final isopropanol flush, the settling chamber and light cell are drained, the coalescer is removed from the system, and a jumper line is installed. The flushing procedure is then repeated with a total of 1000 ml of Bayol D. The coalescer housing (cleaned separately) is fitted with new elements and installed for the next test.

This standard flushing procedure leaves an appreciable amount of residual solvent in the lines. For example, it was determined that after the final isopropanol flush the fluid in the recirculating lines still contained more than 0.5% of the fuel from the preceding test, and presumably a comparable holdover of isopropanol carries through the subsequent Bayol D flushes. Actually, some 2500 ml of flushing liquid, in multiple flushes, is necessary to reduce the content of the preceding fluid to below 0.05%.

Considerable effort was expended in attempts to improve the flushing procedure, since it was suspected that residual solvents would have a significant and variable effect on test results. This work will not be discussed in detail since it was subsequently determined that other factors were far more significant in test results. The principal alternate flushing procedure which was used consisted of the use of water followed by benzene.

C. Test Results and Discussion

1. Test Repeatability Studies

Of the more than three hundred tests run in the SwRI program, the majority were concerned with test repeatability. Only the major findings will be discussed here.

Work was started on the separometer by a series of shakedown runs, followed by a round of cooperative testing with the CRC subpanel. Then a second round of testing was initiated with graded coalescer elements as discussed previously; a few other relatively minor changes of equipment and procedure were introduced.

Initial testing at SwRI under these new conditions showed a startling increase of separometer ratings. In particular, Additive K, which had been rated at about 30 in the first CRC subpanel program, now gave an average rating of 79 in four tests at SwRI. Subsequent investigation at SwRI revealed a major problem in repeatability on this additive, with results ranging from 32 to 95. In efforts to establish the cause of this poor repeatability, a systematic investigation was made of the effects of ambient temperature, type of cooler used on the rig, position of the regulating valve, flow rate schedule, and flushing procedure. No clear-cut evidence was found for primary effects due to any one of these variables. Much of this work was concentrated on flushing procedure since it was suspected that residual isopropanol (not removed by the Bayol D in the standard flushing procedure) was responsible for the erratic results. A flushing procedure was adopted in which no isopropanol nor other mutual solvent was used, relying on successive flushes with water and benzene to clean the rig. This procedure apparently brought the separometer ratings back to the original level in the 30-40 range and improved repeatability somewhat. This procedure was used in running tests at SwRI on all of the additives in the second CRC cooperative program as discussed in the following section.

In subsequent work, poor repeatability was again encountered, and a number of other factors were examined for possible effect on rating level and repeatability. These included back-pressure regulator position and condition, source (lot) of coalescer elements, and water holdup in the fuel tank. The water holdup apparently was caused by progressive contamination of the 100-mesh stainless steel screen in the bottom of the tank.

None of these variables appeared to be the sole source of the difficulty. Also, it was demonstrated conclusively that the flushing procedure was not a critical factor in results.

An analysis of the data indicated that a combination of blend aging and water holdup at the fuel tank screen was the source of the repeatability difficulties on Additive K. Up to this time, no accurate records had been kept on blend age. Usually, up to two gallons of test fuel would be blended with inhibitor; this batch might stand overnight or over a weekend before it was completely used up in testing. All blending and storage was carried out in glass containers throughout the program. A rather large number of tests was run to establish trends on aging the blends containing Additive K and to investigate the relationship between tank screen condition, water holdup, and separometer rating. The following conclusions were drawn:

(1) With normal flushing procedures, water holdup at the tank screen occurred unpredictably. Water holdup may be eliminated by acid-cleaning the fuel tank screen or, of course, by removing the screen entirely.

(2) Water holdup was associated with higher separometer ratings. Comparing results without regard to blend age, the following average values and standard deviations were noted:

No water holdup observed (19 tests):	47 ± 11
Water holdup observed (9 tests):	65 ± 11

(3) There was a definite trend toward lower separometer ratings as the blend containing Additive K was aged. This was qualitatively evident from the earlier tests, and a quantitative comparison was made on later tests on blends of known age, using only those tests in which water holdup had been eliminated. The following average values and standard deviations were observed:

Fresh blends (2 tests):	56 ± 0.5
Blends aged 72+ hours (8 tests):	37 ± 5.5

On the aged blends, the number of tests is sufficient to establish that test repeatability was considerably improved when both blend age and water holdup were controlled in the comparison.

(4) Although insufficient data are available to establish the critical period of aging, it was noted that four blends aged 16 to 24 hours gave ratings almost as low as those aged 72 hours

or longer. Therefore, it is probable that most of the interaction or aging effect occurred in the first 24 hours after adding the inhibitor.

Further discussion of the effect of blend aging will be deferred until a following section.

In considering practical means of overcoming the problem of water holdup at the fuel tank screen, neither acid cleaning nor operating without the screen is very attractive. For acid cleaning, it is necessary to remove and reinstall the screen each time; this is too time-consuming for a test of this type. Operating without the screen introduces some danger of pump damage. Further, it tends to aggravate a problem somctimes noted due to "slugging" of water in the first few seconds of the flow period. It is believed that the water, depending on point of addition, may hit the screen in a fairly massive dose; then, because of the dead spaces in the back-pressure regulating valve and in the line from it to the needle flow-control valve, a large portion of the water may fail to be mixed into the fuel. This settled-out water may then either remain in the regulating valve or may partially "slug" through when flow is started to the coalescer. It is believed that the filter screen helps to break up the first dose of water and minimize accumulation. It is understood that current work of the CRC subpanel has been aimed at standardization of the method of adding water, using a pipette and adding the water at a definite point in the tank. In all of the SwRI tests, water addition has been by pipette, but the point of addition was not absolutely standardized.

The water holdup which has been observed at the filter screen appears to be related to the development of a hydrophobic surface. In addition to the effect of such holdup in changing the proportions of the water-fuel emulsion, there has been some concern about the possible functioning of the screen as a coalescer, thus feeding a partly-coalesced emulsion to the test section. The fuel flow from the tank to the coalescer goes through the pump and the body of the back-pressure regulating valve, but does not pass through the orifice of this valve, which is assumed to be the primary point of emulsification in the recirculated stream.

At this point in the program, a new filter screen was installed in the tank. Very surprisingly, no water holdup was observed in any of the 106 tests performed subsequently. These tests included all of the additives tested previously, so it is difficult to see how the problem could have been caused by "poisoning" of the screen surface by a specific additive. During the period when water holdup at the screen was being encountered, its occurrence appeared to be completely random, and no logical explanation has been found.

Water holdup may also occur on the sloping bottom of the tank; this is observed mostly with highly-refined additive-free base stocks. It is also suspected that major amounts of water are held up in the body of the back-pressure regulating valve and possibly in the line from this valve to the flow-control valve. During the latter part of the program, data were recorded on the volume of water recovered in the settling chamber. It was found that with highly-refined additive-free base fuel only 1 to 3 ml of water were recovered during the entire test, in contrast with the theoretical recovery of 15.6 ml. Thus, the emulsion being fed to the coalescer contained only 0.1-0.2% water instead of the nominal 1%. Additive-blended fuels gave somewhat higher water recovery, in the order of 4 to 8 ml. Since tests on additive-containing blends are associated with water carry-through, it is not possible to assign a firm "theoretical" value to the settling-chamber recovery. In general, water recovery data were very erratic; the following illustrate two of the extreme types of deviation from theoretical behavior:

	Theoretical for Complete Recovery	Soltrol 130	Soltrol 130 + Additive G
Separometer rating	(100)	100	57
Total water collection, ml, at end of successive flow periods	2	0.5	6
	4	--	6+
	6	--	7+
	8	--	--
	10	2	8
	13	--	8
	16	--	8

In tests on relatively heavy highly-refined materials such as Soltrol 130, it is probable that most of the water never becomes mixed with the fuel, but is held up on the bottom of the tank and elsewhere. In some tests on additive-containing fuels, as illustrated for Soltrol 130 plus Additive G, it is evident that a large slug of water comes through upon first opening the flow-control valve. It was considered possible that some of the water holdup problems were associated with the design of the back-pressure regulating valve. However, an attempt to reduce such holdup by filling the chamber of this valve with Woods metal was completely unsuccessful, and, in fact, appeared to increase the amount of initial slugging; probably elimination of the dead space in the valve simply favored the accumulation of water in the take-off line.

It is felt that the present method of preparing the emulsion and feeding it to the coalescer introduces some nonrepeatability into the test procedure, in view of the erratic water collection that has been observed. It is possible that a direct takeoff from the pump discharge line would be a superior method of feeding the emulsion to the coalescer; however, this possibility has not been studied experimentally.

3. CRC Cooperative Programs

As a part of the over-all contractual effort, SwRI participated in the work of the CRC - Aviation Panel on Water Separation Tests and in two cooperative programs of the Separometer Subpanel. One of the test fuels (Gulf Coast JP-4 designated as RAF-151-60) and most of the additives used in these programs were furnished by SwRI as a part of this work.

The initial program of the CRC subpanel was concerned with checking out the rigs as supplied, using several additives to give a wide range of ratings. SwRI data obtained at that time are included in Table 11. This program was run with ungraded coalescer discs as described previously. Nevertheless, the agreement among laboratories was reasonably good, and did demonstrate that additives were rated in the same general categories of performance by all laboratories.

The second CRC program included the use of graded coalescer elements and slight changes in equipment and procedure. The SwRI results obtained in this program are shown in Table 12. These results were obtained using the benzene water flushing procedure discussed previously. It should be noted that other laboratories retained the standard flushing procedure for this program.

Although a discussion of the over-all results of the CRC program is outside the scope of this report, it may be noted that effects of blending procedures and aging were observed by other laboratories, and were believed to be responsible for some of the discrepancies observed. Since these problems were unrecognized at the beginning of the program, no standard procedures had been adopted; it is probable that wide variations in procedure occurred among the laboratories. All SwRI tests were run on blended-in-glass samples, adding the inhibitor to the fuel and stirring until dissolved. Most of the tests were run on fresh blends, but in the SwRI tests at that time no definite control was exercised on aging period. At least one laboratory in the CRC subpanel used stock solutions of the inhibitors, adding them to the base fuel immediately before starting the test. It is understood that in current CRC programs the sample blending and handling procedures have been standardized, so that the test itself may be evaluated without added complications. As will be discussed in the following section, aging or interaction effects have been found to occur with several inhibitors. Therefore, it is very possible that the inherent reproducibility of the separometer test among laboratories is considerably better than that demonstrated in the early programs.

The problem of water holdup in the tank has also been noted by other laboratories. In some of the more recent CRC work, this problem was eliminated by running without the filter screen.

TABLE 11. SwRI RESULTS IN FIRST PROGRAM ON WATER SEPAROMETER

Equipment used as received
Standard flushing procedure
Original six-step flow rate schedule
Fuel temperatures below 90°F in all tests

Base Fuel	Additive[a]	Average Meter Readings
Bayol D	None[b]	99
Esso turbine fuel	None[b]	100, 100
"	B[b]	52, 90
RAF 151-60 (Gulf Coast JP-4)	None[b]	100, 100
"	A	80, 61, 35
"	B[b]	92, 91, 78, 87, 96, 99
"	C	2, 2
"	D[b]	89, 99
"	E[b]	100, 95
"	F	100, 95
"	G	66, 46
"	H	10, 11
"	J	16, 14
"	K[b]	32, 50, 40, 34, 54
"	L	27, 45
"	N	94, 99
"	O[b]	3, 0

(a) Maximum allowable concentration per MIL-I-25017.
(b) Included in cooperative CRC program.

TABLE 12. SwRI RESULTS IN SECOND PROGRAM ON WATER SEPAROMETER

Graded coalescer elements
Water and benzene used for flushing
Revised (seven-step) flow rate schedule
Ambient temperature 70-80°F

Base Fuel	Additive[a]	Average Meter Readings
Esso turbine fuel	None	100
Esso turbine fuel	B	91, 98, 97, 96
RAF 151-60 (Gulf Coast JP-4)	None	100, 99, 100
RAF 151-60 (Gulf Coast JP-4)	B	90, 89, 94, 94
RAF 151-60 (Gulf Coast JP-4)	D	84, 84, 83, 74
RAF 151-60 (Gulf Coast JP-4)	E	99, 99, 98
RAF 151-60 (Gulf Coast JP-4)	K	40, 47, 45, 45
RAF 151-60 (Gulf Coast JP-4)	O	12, 14, 2
RAF 151-60 (Gulf Coast JP-4)	P (0.1%)	99, 100
RAF 151-60 (Gulf Coast JP-4)	Q (0.5%)	98, 98

(a) Maximum allowable concentration per MIL-I-25017, except as indicated.

4 Blend Aging Effects

As described in the preceding section, a definite blend aging effect was discovered as one of the major factors contributing to the poor test repeatability on Additive K. It is quite reasonable to suppose that fuel-additive interactions may occur, depending on the composition of the additive and of the nonhydrocarbon trace constituents of the fuel, and that such interactions either might be quite rapid or might require several hours, days, or even longer to develop fully.

A summary of the test results relating to the aging effect is given in Table 13. This table includes all of the inhibitors tested in JP-4; some of the inhibitors have been run only at zero age. Essentially all of the data shown in Table 13 were obtained after the installation of the new filter screen, so that water holdup was not a complicating factor. It will be noted that of those additives for which adequate data are available, two of them (K and L) showed definite decreases in separometer rating as the blends aged, and three of them (B, D, and G) showed definite increases. Another additive (F) showed a slight increase upon aging which may be significant in view of the improved repeatability demonstrated in recent tests.

The increase of separometer rating upon blend aging was rather spectacular in the case of Additive G, which gave initial ratings of 27-30 and increased to 55-74 after 3 hours and to 79-81 after 18 hours or more. All of the six additives for which adequate data are available do show some aging effect in the JP-4 fuel. The remaining seven additives were not checked for aging effects; they fall at the high or low ends of the separometer rating scale, and hence aging effects would have to be rather extreme to be detected. It is very possible, however, that some of them would show such effects.

The variation of water-separating properties with blend aging time points out the difficulty of rating the apparatus itself when this complication is present. Although it is considered desirable to use actual production fuels for such work, the presence of nonhydrocarbon trace constituents in such fuels does complicate the evaluation of the apparatus.

A question also arises in interpreting the results as applied to the individual inhibitors. For a comparison of the separometer results with those of the single-element tests (which comparison is made in a later section of this report), the fresh-blend separometer results are used. The single-element tests in this program were run on freshly blended fuel-additive mixtures in all cases.

Although no attempt was made to define the chemical reactions involved in the observed aging effects, it was demonstrated rather conclusively that for one particular additive the aging effects were caused by interaction of the additive with polar nonhydrocarbon constituents of the fuel. A

TABLE 13. SEPAROMETER RESULTS ON FRESH AND AGED BLENDS

Base fuel Gulf Coast JP-4

Additive[a]	Separometer Ratings at Following Blend Ages (hr)				
	0	2-3	4-5	18-31	72+
A	29, 32				
B	82	82	90	96	
C	6, 8[b]				
D	74	77		90, 90	
E	99, 99				
F	85	85	89	90	
G	30, 27, 27	74, 55, 60		79	81
H	10, 11				
J	31, 33				
K	45, 55, 57, 56				37[c]
L	52, 41	45	50	37, 21	19
N	98, 98				
O	3, 3				

(a) Maximum allowable concentration per MIL-I-25017.
(b) Blend age unverified.
(c) Average of 8 tests; standard deviation ±5.5.

sample of the Gulf Coast JP-4 fuel was treated by percolation through adsorption-grade alumina (16 ml fuel per gram alumina). Separometer tests on Additive G at maximum concentration in this fuel gave the following ratings in comparison with blends in untreated Gulf Coast JP-4:

	Fresh Blends	Blends Aged 24 hr
Treated fuel	9	14
Untreated fuel	28	79

Thus, the aging effect for this particular additive is indeed due to interaction between the additive and polar trace constituents in the fuel. It will be noted that even the fresh-blend value for the treated JP-4 fuel is much lower than the corresponding fresh-blend value for untreated fuel. This is an indication that the interaction between additive and fuel constituents either has an appreciable effect immediately after blending, or that the interaction becomes significant during the course of the separometer test itself. The "fresh-blend" values, although termed "zero-hour" data, actually represent about 15 minutes between the blending operation and the start of the separometer test.

In the light of these data on Additive G, it appears probable that the aging effects observed with other additives may well be caused by similar interactions. Another phenomenon which has been mentioned as a possible cause of aging effects is the "plating out" of additives, i.e., additive depletion during storage of fuel-additive blends by adsorption of the additive on container walls or other surfaces. It is believed that such depletion is unimportant here, and in any case the decrease of separometer ratings (such as for Additive K) could not be explained on this basis.

Any broader interpretation of fuel-additive aging phenomena is outside the scope of this report. It may be noted in passing that both the freshly-blended and aged characteristics of a given fuel-additive combination may be of practical importance in field fuel-handling equipment. The results discussed here apply only to one particular JP-4 fuel, and it should not be inferred that the same aging characteristics will be given by a particular additive in different fuels.

5. Effect of Additive Concentration

A limited study was made of the effect of additive concentration on separometer ratings, using Additives C and K. The results of this study are somewhat inconclusive because of the occurrence of water holdup in these tests, as discussed previously. Classifying the results according to whether or not water holdup was obtained, the following lineup of separometer ratings is observed:

		Tests with Water Holdup	Tests without Water Holdup
Additive C,	Maximum	8	6
	Intermediate	11	
	Minimum	27, 20	
Additive K,	Maximum	69 (Avg)	56 (Avg)
	Minumum	66	59

All of these test results were obtained on fresh blends. Additive C showed an increase of separometer rating at minimum concentration which is probably significant, although the values of 20-27 are still on the low end of the separometer rating range. The results on Additive K did not show any significant change of rating on reducing additive concentration. As discussed previously in connection with the single-element tests, the minimum concentration is in the order of 30% of the maximum in the case of Additive C, but in the order of 70% of the maximum in the case of Additive K.

6. Reference Fluid Investigations

Although initial experience with the CRC separometer had been moderately favorable in terms of agreement among laboratories, it became evident that some sort of reference fluid or fluids was needed for interlaboratory checks on equipment operation and rating level. The aging effects observed with commercial additives and fuels indicated clearly that such blends are not suitable standards. Ideally, a reference fluid should be readily obtainable, closely specified, inexpensive, and close to commercial fuels in physical properties and hydrocarbon type composition. It may be assumed that any pure hydrocarbon or mixture of hydrocarbons in this range will have a separometer rating of 100 if the equipment is operating properly. This one check point, however, is not a critical test of rig rating level; it is necessary also to have reference fluids in the mid-range where reproducibility is more difficult.

Pure hydrocarbons with physical properties in the jet fuel range are extremely expensive. Some work has been reported by other laboratories on the use of lighter materials such as toluene-isooctane blends as reference fluids. These hydrocarbons are readily available and relatively inexpensive, but their low viscosity introduces operating problems in the separometer.

In general, it does not appear necessary to specify pure hydrocarbons as reference fluids, provided suitable commercial hydrocarbon solvents, free of polar materials, can be obtained. Bayol D, a widely used "refined kerosene" solvent, is no longer available. Three solvents have been examined in the SwRI program for possible use as reference fluids: Sovasol 35, WS-3750, and Soltrol 130. These are all isoparaffinic "odorless" solvents, obtained (so far as is known) from heart cuts of alkylate bottoms. No additives are present in the WS-3750 or Soltrol, but the particular Sovasol used in this program was reported by the supplier to contain a small amount of "antioxidant." The following data are of interest in comparing physical properties of these solvents with the properties of commercial fuels:

	Dist. Range, °F	Gravity, API/60	Viscosity, cs/100°F
Gulf Coast JP-4	140-505	50	0.84
Aviation Kerosene	350-520	41	1.38
Sovasol 35	345-420	--	1.48
WS-3750	430-500	48	2.41
Soltrol 130	350-405	56	1.38
Bayol D	430-500	48	1.85

It will be noted that the Sovasol 35 and Soltrol 130 approximate the viscosity of commercial aviation kerosene, and the WS-3750 is much more viscous.

Separometer results on the three "odorless" solvents blended with various commercial corrosion inhibitors are shown in Table 14. It will be noted that the Sovasol 35 gave consistently low ratings; apparently the presence of the "antioxidant" in this solvent makes it unsuitable as a reference fluid. Percolation through alumina brings this solvent up to 100 separometer rating. It is understood that additive-free Sovasol 35 can be obtained from a different refinery of the same company.

The tests with uninhibited WS-3750 gave ratings of 100. Some of the additive blends in this solvent gave results that were lower than the corresponding results with JP-4. However, the most outstanding change was shown by Additive G. It will be noted that the aging effect observed with JP-4 was completely absent when this additive was blended in WS-3750. In this respect the WS-3750 was similar to the alumina-treated JP-4 described previously.

WS-3750 is somewhat unsuitable as a reference fluid because of its high viscosity. Apart from the question of comparability of results with those on fuels of normal viscosity, there are also operating problems. The WS-3750 cannot be used in the metering systems of the existing separometers; for the tests shown in Table 14, an auxiliary rotameter was used. Also, emulsion formation appears to be somewhat more difficult with this viscous fuel.

The Soltrol 130 gave ratings of 100 on uninhibited fuel, and rated the additives at essentially the same levels as given in corresponding tests in JP-4 fuel. There also appeared to be a slight aging effect on the two additives for which this was investigated. The aging effects were in the same directions as those observed for the corresponding JP-4 blends, but not as pronounced.

TABLE 14. SEPAROMETER RESULTS ON REFERENCE FLUID CANDIDATES

Additive[a]	Separometer Rating[b]			
	Sovasol 35	WS-3750	Soltrol 130	JP-4 (Average)
None	80	100	100	100
	87	100	100	
	81			
	100[c]			
B		67 (0)	78 (0)	82 (0)
C	8 (0)	3 (0)	6 (0)	7
	8 (21)			
D	11 (2)	90 (0)	94 (0)	74 (0)
	10 (3.5)			90 (18)
E		100 (0)	100 (0)	99 (0)
F	17 (0)			85 (0)
	18 (3)			89 (5)
G	9 (0)	10 (0)	29 (0)	28 (0)
		11 (3)	57 (3)	63 (3)
	10 (29)	15 (24)	43 (24)	79 (24)
K	27 (0)	23 (0)	63 (0)	53 (0)
	22 (0)	32 (3)	53 (3)	
	24 (29)	33 (24)	54 (24)	
	15 (144)			37 (72+)
O			13 (0)	3 (0)
			10 (0)	

(a) Maximum allowable concentration per MIL-I-25017.
(b) Numbers in parentheses represent fuel-additive blend age in hours.
(c) Fuel percolated through alumina.

The very preliminary work done on base stocks for reference fluids is not sufficient to make any firm recommendations. Of the three solvents examined, Soltrol 130 appears to be the most suitable. However, the aging effect observed with some of the additives is a source of concern. It may be that some sort of a final cleanup operation in the laboratory will be necessary to insure against all polar contaminants, regardless of what base stock is specified. There is no standard quality test that can be applied to purchased material, other than separometer performance, to define its suitability. The use of a separometer test as a specification for the purchase of reference fluid for the separometer would be meaningless.

Further work on reference fluids is being carried out through CRC cooperative action. In addition to specifying a suitable base fluid, it will be necessary to specify a suitable additive or additives for obtaining the standard fluids for the intermediate rating range. The commercial corrosion inhibitors used in the SwRI program are not suitable for this purpose because of lack of any firm specification on composition. Most of the compositions are proprietary, and in any case are believed to be insufficiently standardized for use in reference fluids.

Although reference fluids would be desirable for rig standardization and checking reproducibility, it is our opinion that they are not absolutely essential for this purpose, and that any extensive effort in their development is not justified.

Another potential use of a standard base fluid would be as a material in which new additives (or production lots of present additives) could be checked for their effect on water separation. For such use, the Soltrol 130 appears quite attractive, since the additives tested were all rated at approximately the same levels as in JP-4. It is believed that such use of a standard base fluid is of considerable value, and more work in this direction would be desirable. Although no standard-fluid evaluation of an additive could possibly predict performance in all commercial fuels, such an evaluation would at least serve to weed out poor materials.

7. Tests on High-Temperature Fuel

In a brief study of the separometer's capability of evaluating a high-density high-viscosity fuel, duplicate tests were run on HTF-27 (isopropylbicyclohexyl). This material is much heavier than any of the fluids previously run in the separometer, having an API gravity of 28 and a viscosity of 6.3 centistokes at 100°F. It was necessary to use an auxiliary rotameter for this material.

Excellent coalescence was obtained; the duplicate tests gave ratings of 98 and 99. However, the initial emulsion formed by recirculation did not appear to be as dense or stable as those obtained with JP-4. Also, it was observed that at the higher flow rates there were relatively large droplets of water (or possibly fuel-water) which rose slowly through the settling chamber. These droplets were eventually carried into the turbidity cell and caused fluctuation of the meter but no permanent deflection. It appear probable that the velocities in the settling chamber are too high for a fuel of this density and viscosity. Fuels of this type could be evaluated in the separometer in its present form,provided the flow rate schedule is modified to exclude the higher flow rates. An alternative solution would be the use of a larger settling chamber to reduce velocities. If any extensive work were done with this type of fuel in the separometer, it would be desirable to improve the method of emulsion formation. The tests performed here have indicated that the separometer can be adapted to evaluation of such fuels, by modifications similar to those indicated.

V. COMPARISON OF SEPAROMETER AND SINGLE-ELEMENT RATINGS

Having identified and corrected the factors contributing to separometer nonrepeatability, it was possible to obtain a firm comparison of separometer and single-element ratings on the additives. Table 15 gives a listing of recent separometer tests on all of the corrosion inhibitors, and the corresponding single-element ratings based on effluent clarity. The separometer ratings in the table all represent tests in which no water holdup was evident. Further, in cases where an aging effect was noted, the separometer ratings in the table all represent fresh-blend data. This latter restriction was observed since the entire single-element program was run on fresh blends. It should be pointed out again that the aging characteristics of a particular fuel-additive combination may be of utmost importance in determining its suitability for some particular use; however, for the purposes of this program, aging characteristics are merely a complicating factor which has necessarily been eliminated or equalized to obtain valid comparisons.

As shown by the results listed in Table 15, the most recent separometer ratings (observing the restrictions mentioned above), show excellent repeatability, the spread between duplicate tests being 3 units or less on all inhibitors except the K and L, these inhibitors (which are in the difficult mid-range of rating and also show aging effects) give a spread of 7 to 10 units in duplicate tests. The ratings shown in Table 15 for Additive D, averaging 87, are considerably higher than the ratings in the 70's that have been reported previously for fresh blends of this additive. However, the higher ratings have been verified by additional rechecks and appear to be the most reliable results.

In considering the degree of correlation of the separometer ratings with the single-element ratings, it will be observed that the additives fall into two broad groups. The group with the better performance showed separometer ratings of 82 to 99 and a total of 2.0 to 4.5 satisfactory single-element ratings. Within this group, the single-element tests showed somewhat sharper discrimination among the additives than did the separometer tests. For example, it is believed that the distinction between a 4.5 and a 3.5 rating in the single-element tests represents a significant difference in performance level, but that the corresponding 99 and 98 separometer ratings are indistinguishable. Although no proof can be advanced, it is believed that it would be advantageous to modify separometer procedures to "spread out" this upper end of the scale with the aim of obtaining more discrimination. It is noted that the order of rating additives in this group is exactly the same for both tests. Although this is probably fortuitous (in view of the small differences in both separometer and single-element ratings), it is still very encouraging.

TABLE 15. COMPARISON OF SEPAROMETER AND SINGLE-ELEMENT RATINGS

Gulf Coast JP-4 fuel

Additive[a]	Satisfactory Single-Element Effluent Ratings[b]	Separometer Ratings
E	4.5	99 (99, 99)
N	3.5	98 (98, 98)
D	2.5	87 (89, 85, 88)
F	2.5	85 (85, 85)
B	2.0	82 (82, 82)
A	1.0	30 (29, 32)
G	1.0	29 (30, 27, 27)
K	0	50 (45, 55)
L	0	48 (52, 45)
J	0	32 (31, 33)
H	0	10 (10, 11)
C	0	7 (6, 8)
G	0 (1 test)	3 (3, 3)

(a) Maximum allowable concentration per MIL-I-25017.
(b) Number of satisfactory effluent cloud ratings, out of five possible (series with A/C test dust and water).

The group of additives with relatively poorer performance in both tests includes single-element ratings of 1 and 0, and separometer ratings from 3 to 50. The order of rating by the two methods is not the same, since Additives A and G (each showing one satisfactory single-element test) were rated lower in the separometer than some of the other additives which gave no satisfactory single-element tests. This discrepancy is not considered serious, in view of the many modes of failure which are observed in single-element tests. That is, a particular additive-element combination may give a failing single-element test by failure of water-coalescing action, by passage of solid particles at low pressure drop (probably due to the dispersing action of the additive), or by passage of solid particles at high pressure drop. The separometer evaluates the relatively simple phenomenon of water coalescence without the complication of solid contaminant. Further, the single-element ratings are made on a go-no-go basis which demands essentially perfect performance at a given set of conditions; the separometer ratings are based on the "extent of failure" over a range of flow rates. Another difference between the two types of test is the flow system. In the separometer, the fuel and water are premixed, and flow through the coalescer is single-pass. The single-element tests operate with continuous injection of contaminants and recirculating flow. In this respect the single-element tests suffer from the same basic disadvantage as that observed in full-scale filter-separator testing. The recirculating fuel system is an artificial device, not encountered in field operation, which conceivably can give fictitious results because of cumulative buildup of solids or cumulative extraction of additive and fuel constituents.

In view of the many differences between the two methods of evaluation, the degree of correlation appears to be satisfactory for the additives tested at maximum allowable concentration. The studies of effect of concentration have been very limited, however, they have revealed one example on Additive C in which the two methods of evaluation do not correlate, as shown by the following:

	Maximum Concentration	Minimum Concentration
Average separometer rating	2	24
Single-element results:		
Number of element types tested	5	1
Number of element types giving satisfactory tests	0	1

It can be seen that the reduction of concentration gave a satisfactory single-element test, but did not raise the separometer rating to the level usually associated with satisfactory performance. Thus, this may be an example of poor correlation between the two types of test. Additional single-element tests would be required for confirmation.

With this one exception, the degree of correlation appears to be satisfactory. This correlation increases confidence in the use of the separometer as a screening device to evaluate additives or specific additive-fuel combinations.

VI. CONCLUSIONS

The single-element tests run in this program have indicated very definite differences in the effect of various additives on water and dirt removal, and also definite differences among the efficiencies of various types of filter-separator elements. The presence of corrosion inhibitors was generally detrimental, particularly on water coalescence and separation. Filter tests with iron oxide contaminants usually showed less effective performance, and some reversals of relative additive ratings were noted (in comparison with tests with the A/C dust). The use of red iron oxide plus 0.5% water gave the most severe conditions for filter-separator performance.

There was a general relationship between the effect of an additive on interfacial tension and its effect on water separation, but two of the twelve inhibitors did not follow this general correlation.

At minimum allowable concentration, three out of five additives which had failed at maximum concentration showed entirely acceptable results in comparable tests (A/C dust and water). Fuel aromatics content and gravity, within JP-4 specification limits, did not show any effect on coalescence or solids retention, but there was a marked effect on filter plugging (in tests with A/C test dust and water).

The program with the CRC water separometer has shown a very encouraging correlation with the single-element test ratings based on effluent clarity. Severe difficulties in separometer test repeatability were encountered in the early part of the program; however, most of these were the result of interactions between fuel and certain additives and cannot be attributed to any difficulty with apparatus or procedure. Some minor revisions of the separometer test would be desirable to further improve repeatability, such as detailed standardization of the procedure for emulsion formation and the elimination of water holdup in this system. The latter would require equipment modification, and may not be fully justified to date by the results obtained.

In a limited search for a separometer reference fluid, the most attractive candidate tested was Soltrol 130, a commercially-available alkylate cut. A reference fluid would be very convenient for screening experimental additives, but such a fluid is not absolutely essential for purposes of standardizing equipment and procedure.

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Southwest Research Institute, San Antonio, Texas. EFFECT OF JET FUEL ADDITIVES ON FILTERABILITY AND WATER SEPARATION CHARACTERISTICS, by Robert K. Johnston and J. P. Cuellar, Jr., June 1961 67 pp. incl. figs. and tables. (Proj. 3048; Task 30178) ASD TR 61-345) (Contract AF 33(600)-39425). Unclassified Report.

The effect of corrosion inhibitors on filtration and water separation characteristics of JP-4 fuel was studied in a single-element filter-separator test facility, using five types of commercial elements and housings designed to simulate full-scale flow conditions. Standard coarse A/C dust

(over)

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and water were the major contaminants studied, with some work on iron oxides. Adverse effects of the corrosion inhibitors varied widely, and the element types differed in efficiency and modes of failure.

The CRC water separometer, a bench-scale apparatus, gave a general correlation with the single-element results. Interaction of additives with fuel constituents caused difficulty in early work, but otherwise the separometer repeatability was satisfactory. Preliminary work on a reference fluid indicated that an "odorless solvent" may be suitable.

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